

Grosenbaugh

PLANTING THE SOUTHERN PINES

Philip C. Wakeley

VOLUME 1

Planting Policies

Seed



SOUTHERN FOREST EXPERIMENT STATION

Chas. A. Connaughton, Director

New Orleans, La.

FOREST SERVICE, U.S. DEPT. OF AGRICULTURE

NOTE

This is a preliminary edition of a manuscript intended for review and later publication as a bulletin of the U. S. Department of Agriculture. It is being released in this form to make its contents available for immediate use in the South's rapidly expanding program of forest planting.

Since Departmental publication will supply the bulk of the demand, this edition has been kept small. With few exceptions, copies can be furnished only to organizations.

The manuscript is complete in these three volumes, except that no photographs have been included.* Literature citations have not yet been numbered, but the text supplies enough information to allow identification of each reference in the list beginning on page 429.

It will be appreciated if errors in the manuscript are reported to the Southern Forest Experiment Station.

* Most of the photographs may be purchased from the Forest Service, U. S. Department of Agriculture, Washington 25, D. C. The captions in the text include the order number of all Forest Service pictures except the following: fig. 1, F465213; fig. 2, F465214-15; fig. 3, F275948, F465216; fig. 5, F465217-18; fig. 8, F465219-22; fig. 9, F465223; fig. 12, F465678, F465225; fig. 13, F310759; fig. 17, F352955; fig. 20, F465136; fig. 26, F465679-80.

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PLANTING THE SOUTHERN PINES ^{1/}

^{1/} Supersedes U. S. Dept. Agr. Tech. Bul. 492, Artificial Reformation in the Southern Pine Region. 1935.

Philip C. Wakeley

Forester, Southern Forest Experiment Station, Forest Service

Planting the southern pines offers the only sure way of restoring to timber production, within the next 50 years, a huge area of forest land vital to the southern and the national economy.

By conservative estimate, the area in the South still in need of planting is 13 million acres, nearly all of which (Wakeley, 1945) (____) ^{2/} should be planted with the southern pines (table 1). Every

^{2/} *Italic numbers in parentheses refer to Literature Cited, pp. 429 to 497.*

State from Virginia to Texas has substantial portions of land desirable to plant for timber production or erosion control. Much is on farms and much is industrially owned. A very sizeable portion is in the hands of small investors, and some is in public holdings. In brief, planting is almost everybody's business.

Table 1.--Estimate, by States, of acres desirable to plant 1/

State or region	: Idle or : abandoned : farm : land <u>2/</u>	Forest land, by major forest types				: Total farm and forest land
		: Longleaf; : longleaf- : slash	: All loblolly : and shortleaf : types <u>3/</u>	: Upland : hard- : wood <u>4/</u>	: Bottom- : land : hardwood	
Virginia Piedmont	110,200	...	135,400	125,600	5,500	376,700
North Carolina	163,400	74,000	558,800	74,000	22,100	892,300
South Carolina	295,700	80,300	344,700	38,000	12,700	771,400
Georgia	728,200	693,600	293,000	81,900	13,700	1,810,400
Florida	181,100	2,950,600	60,200	94,700	26,500	3,313,100
Alabama	677,200	276,900	542,600	212,000	11,400	1,720,100
Mississippi	1,059,600	504,100	234,300	164,400	11,400	1,973,800
Louisiana	107,600	716,300	156,300	39,800	54,600	1,074,600
East Texas	197,000	138,300	164,400	63,500	10,200	573,400
Arkansas <u>5/</u>	204,400	...	86,300	69,900	49,100	409,700
Southeast Oklahoma	45,600	...	40,700	59,000	2,000	147,300
Total	3,770,000	5,434,100	2,616,700	1,022,800	219,200	13,062,800
Percent of total	28.9	41.6	20.0	7.8	1.7	100.0

1/ The estimates are conservative, but are comparable between States. They were derived before wartime over-use had increased the area in need of planting. They include only land considered silviculturally and economically desirable to plant. They omit the outlying portions of the southern pine region and areas likely to be needed for higher agricultural use. Source: Southern and Appalachian Forest Surveys, Forest Service, U. S. Dept. Agr., 1933 to 1940, inclusive. For more recent estimates for portions of the South, see (McCormack, 1949; McC., 1949; McC., 1950; McCormack, 1950; Ross, 1948) (____, _____, _____, _____, _____).

2/ Exclusive of that in the Delta portions of Mississippi, Louisiana, and Arkansas.

3/ Including those with hardwoods in mixture.

4/ Exclusive of the Mountain Unit of the Survey in North Carolina.

5/ Except the northwest part, not covered during 1933 to 1940.

Large-scale planting of southern pines is a comparatively new enterprise. A few small plantations were established before 1900, but the total area successfully reforested by 1920 probably did not exceed 500 acres. Large-scale planting got under way in the 1920's and was greatly speeded up in the middle and late 1930's. Since World War II the annual rate of planting has exceeded that of the best prewar years.

The planting that has been done so far is only a good start on the whole job, less than one-tenth. Planting the huge acreage that remains will be no simple or easy task, but neither will it be an impossible one. Experience has shown that it can be done at a reasonable cost. Southern pines are hardy species, adapted to grow vigorously on sites unfavorable for many other plants, and remarkably able to resist or recover from injury. Common sense, observation, and hard work led the early planters to some notable successes (figure 1). Today's planters have one additional resource--a considerable body of knowledge and skill drawn from research and practice.

Figure 1.--Part of an 853-acre slash pine plantation at Bogalusa, Louisiana, photographed 24 years after its establishment in 1924-25.

This bulletin summarizes the technical knowledge that is now available. The information has been drawn from many sources, but the bulk is from studies conducted by the Southern Forest Experiment Station since 1922 and from records of Region 8, U. S. Forest Service. A number of the research findings from these studies are being published for the first time. The great majority of the studies and observations cited from other sources have not previously been evaluated between one set of covers.

The successive steps in planting are taken up in the order in which they are usually carried out. The first chapter discusses the bases for policy decisions, most of which must be made before a planting job is started. The second chapter deals with seed. The third concerns nursery practice. The fourth relates to field planting, and the last discusses the protection and early care of plantations.

Although pine planting in the South will not be entirely restricted to the principal southern species, they will receive the main emphasis for some years to come. For this reason, the bulletin is limited to loblolly, slash, longleaf, and shortleaf pine. The five other southern pines are only mentioned incidentally.

PLANTING POLICIES

The success of any planting program depends upon fundamental decisions of policy that must be made before a pound of seed can be bought or a square foot of soil turned. The discussion in the sections immediately following is intended as a guide to such matters as the selection of species, choice of spacing, means of procuring suitable planting stock, and determination of plantable land. Costs of planting and plantation yields are briefly discussed, as well as the urgent need for maintaining records and observing safety practices.

SPECIES CHARACTERISTICS THAT AFFECT PLANTING

A choice between species must be made in most planting programs, since two or more species may be suitable on two-thirds of the plantable acreage. The essential thing is to choose a species well adapted to the local climate and sites and the local pattern of fire, insects, diseases, and other hazards. Such adaptation is far more important than hypothetical differences in average rate of growth, strength of wood, and the like. The one clear exception to this rule is in plantations established for gum naval stores, for which either longleaf or slash pine must be used.

Loblolly Pine

Among the four principal southern pines, the range of loblolly (Pinus taeda L.) is second only to that of shortleaf in extent. It includes the Coastal Plain from New Jersey to Florida and Texas, and the Piedmont, and it runs north in the Mississippi Valley to Tennessee, Arkansas, and Oklahoma.

The advantages of loblolly pine for planting include, in addition to its wide range and usually high yields, the ease with which its seed can be extracted, cleaned, and stored; the ease of management in the nursery; its good initial height growth after planting; its relative resistance to brown spot needle disease (caused by Scirrhia acicola [Dearn.] Siggers) and infrequent injury by hogs; its adaptability to a great variety of sites (including many types of eroding sites); its superiority to shortleaf in controlling erosion by heavy needle-fall; its relative resistance to injury by sleet and snow (Abel, 1948; McKellar, 1942; Muntz, 1947; Muntz, 1948) (____, ____, ____, ____); and the likelihood of aggressive natural reproduction in subsequent rotations.

Loblolly is not, however, as abundant or regular a seed producer in the inland portions of its range as was formerly supposed (Hall, 1945; Wakeley, 1947) (____, ____). Its cones are difficult to detach from the trees and expensive to collect. Its seed is subject to dormancy and frequently requires special treatment to stimulate germination.

Loblolly is highly susceptible to the southern fusiform rust (caused by Cronartium fusiforme Hedgc. and Hunt). The rust cankers cause some mortality and appreciable loss of production from defect, even though loblolly is less easily killed than slash pine by this disease (Lamb and Sleeth, 1940)(____). After shortleaf pine, loblolly is the species most seriously affected by littleleaf disease (Hepting, Buchanan, and Jackson, 1945)(____). It is extensively bitten back by rabbits immediately after planting and attacked seriously by Nantucket tipmoth (Rhyacionia frustrana Comst.). It is the most susceptible of the four principal southern pines to injury by fire. Planted loblolly pine is likely to be rougher and limbier than planted slash pine.

Despite its good survival and growth on a great variety of soils, loblolly seems less well adapted than shortleaf to the drier sites in the northern and western parts of its range. It is inferior to slash on poorly drained sites in the southern part of its range, and to longleaf on deep, dry, sterile sands. In many parts of Mississippi, Louisiana, and Texas it is also less well adapted than either longleaf or slash to large areas of former longleaf pine sites having sandy or fine sandy loam surface soils underlain at shallow depths by stiff subsoils.

Slash Pine

The natural range of slash pine (Pinus caribaea Morelet) in the United States is limited to the Coastal Plain from southern South Carolina to Florida and west nearly to the Mississippi River.

Planting has extended the range to parts of North Carolina, northern Alabama and Mississippi, western Louisiana, southern Arkansas, and eastern Texas. Early apprehensions about the ability of slash pine to produce viable seed and to reproduce itself naturally in these localities seem to have been unfounded (Anderson, 1948; Rosenkrans, 1944; Weddell, 1939)(____, ____, ____). Nevertheless, widespread ice damage, and certain deficiencies in form and growth rate (Claridge, 1933)(____), cast some doubts on the soundness of wholesale planting of slash (especially for saw timber) beyond its native range, even in western Louisiana and eastern Texas. A final opinion on this point must await further observation and research.

Within and near its natural range, slash pine is a relatively good seed producer. Its seed is easy to collect, extract, clean, and store, and seldom becomes strongly dormant. The species is easy to manage in the nursery. It is a moist-site species, adaptable to a great variety of sites, except the very dry. Planted seedlings make rapid initial growth, are highly resistant to tipmoth, and soon attain (Simerly, 1936; Squires, 1947)(____, ____) fairly high resistance to fire. Planted slash pine prunes itself better than planted loblolly (Muntz, 1948)(____). Littleleaf disease has not yet been reported on slash pine, though perhaps only because few or no slash plantations have reached susceptible ages in the littleleaf territory. On favorable sites, slash pine has excellent possibilities of aggressive natural reproduction in subsequent rotations. The vigor and uniformity of its early growth, and its value for naval stores, have made it the favorite species for planting in the lower South.

Despite slash pine's excellent showing in young stands and the wide and favorable publicity it has received, it still offers some problems. In many nurseries it is subject to heavy infection by southern fusiform rust. In some nurseries and on adverse planting sites it is rather susceptible to brown spot. It is extensively bitten back by rabbits; injury by leaf-cutting ants is more often fatal to newly planted slash than to newly planted longleaf seedlings; and slash plantations up to at least five years old may be seriously damaged by hog-rooting (Hopkins, 1947)(____). Southern fusiform rust infects slash pine in plantations at least as heavily as it does loblolly, with much higher mortality among infected trees (Lamb and Sleeth, 1940)(____). Ice storms (sleet or "glaze"), with or without snow, injure slash much more seriously than any of the other three principal southern pines (Abel, 1948; McKellar, 1942; Muntz, 1947; Muntz, 1948)(____, ____, ____, ____). Under comparable conditions, slash is the least windfirm of the southern pines (Cockrell, 1936)(____).

Slash pine undoubtedly owes part of its popularity to its almost universally clean, vigorous appearance the first few years after it has been planted. In its proper place, slash pine is indeed an ideal tree to plant. But in zones of extreme rust infection or severe ice storms, or on the drier, less fertile longleaf sites, or far beyond its natural range, it has by no means always fulfilled the promise of its good initial growth.

Longleaf Pine

Longleaf pine (Pinus palustris Mill.) occurs in the Coastal Plain from Virginia to southern Florida and west to eastern Texas, with extensions into northwestern Georgia and central and northern Alabama.

The three chief advantages of longleaf pine for planting are its acceptable rate of growth on large acreages where other species grow poorly or not at all, its infrequent infection by southern fusiform rust (Siggers, 1946; Siggers, 1947; Siggers and Lindgren, 1947; Sleeth, 1943)(____, ____, ____, ____), and especially its remarkable resistance to fire (Wahlenberg, 1946)(____). Its apparently high resistance to littleleaf disease (Hepting, Buchanan, and Jackson, 1945)(____) may also prove to be a great advantage.

Longleaf seedlings, especially in the "grass" stage, frequently sprout and recover after various types of injury. Longleaf is virtually untouched by rabbits and tip moth and is seldom injured much by sleet and snow (McKellar, 1942; Muntz, 1947; Wahlenberg, 1946, p. 186)(____; ____; ____, page 186). Contrary to impressions given in the literature, it has usually been easy to get enough longleaf seed. Longleaf is less subject than any other southern pine to stagnation of growth through overcrowding.

Despite these merits, longleaf is in many ways more difficult to plant than the other southern pines.

Longleaf cones are heavy and bulky to collect and ship. Incorrect cone storage and too high a degree of heat in extracting kilns can easily injure the seed, which also is difficult to clean and extracting as to storage requirements. Nursery spraying to control brown spot is almost always essential. The greater size and weight of longleaf seedlings makes them about half again more expensive to ship than slash or loblolly.

First-year survival is often more difficult to attain with longleaf than with other species (Ware and Stahelin, 1946; Ware and Stahelin, 1948)(____, ____). The seedlings usually remain "in the grass" for 3 to 5 years, and, where brown spot is severe and prescribed burning (p. 399) is neglected, frequently for 10 years and sometimes for 20 or more (Wahlenberg, 1946; Wakeley and Muntz, 1947)(____, ____). This habit places longleaf at a disadvantage in comparison with other southern pines (figure 2). It handicaps it in competition with hardwood sprouts and brush (Stahelin, 1946)(____) and even with grass and weeds, and keeps it for long periods in a stage susceptible to brown spot and hogs. Where height growth is unduly delayed, mortality is likely to continue annually for many years (figure 2B). In contrast, plantations of other species ordinarily suffer little mortality between first-year establishment and the closing of the crowns, unless from unusual epidemics or from fire.

Figure 2.--Comparably spaced longleaf (left) and slash pines: A, 14½ years after planting at Auburn, Alabama; and B, 20 years after planting at Bogalusa, Louisiana. A shows a common and B an extreme contrast in survival, growth, and crown canopy of the two species.

It is essential to fence young longleaf plantations against hogs to prevent serious loss, and against sheep and goats to prevent their deforming the trees by biting out the buds. The cost of controlling pocket gophers (Geomys spp.) and leaf-cutting ants (Atta texana Buckley) is most likely to occur in longleaf plantations, because these pests prefer longleaf sites.

The establishment of the next rotation by natural reproduction is harder and less certain with longleaf than with any of the three other principal southern pines.

While they must be recognized, these difficulties should not be over-stressed. Longleaf pine is capable of high survival and good early growth (figure 3). It survives and grows better than other species on certain sites, and at least as well as other species on many more. About 40 percent of the plantable acreage in the South lies in the longleaf pine types (table 1), where climate and the grasses and brush naturally associated with longleaf combine to make fires start easily and spread fast. On these sites planting loblolly or slash does not decrease the inflammability of grass and brush (Chapman, H. H., 1936)(____) and the risk remains too great for these pines. The high resistance of longleaf to fire, combined with its good qualities as timber, its value for naval stores, and its low susceptibility to fusiform rust and to climatic injury, more than offsets its less desirable characteristics. Post-war planting programs show an encouraging tendency toward increased use of longleaf pine.

Figure 3.--Survival and growth of longleaf pine under near-optimum conditions. H. C. Thompson plantation, St. Tammany Parish, Louisiana, photographed from same point 5 and 18 years after establishment.

Shortleaf Pine

Shortleaf pine (Pinus echinata Mill.) has the widest natural range of the four principal southern pines. Its northern range extends from extreme southeastern New York State and eastern and southern Pennsylvania through West Virginia, southern Ohio, Kentucky, southern Illinois, Missouri, and Oklahoma. It goes south to northern Florida and eastern Texas.

Shortleaf pine is adapted to a great variety of sites, including some of the more sterile or eroded soils in dry localities (Cooper, 1942; Minckler, 1943; Minckler, Ecol. Monog., 1946)(___, ___, ___), and at the higher elevations. The seed is easily extracted, dewinged, cleaned, and stored. Hogs seldom injure the seedlings. Although its initial growth is less aggressive than that of loblolly, shortleaf sprouts when it is killed back by fire during the first 3 or 4 years of growth (Moore, 1936; Nelson, Ralph A., 1940)(___, ___); this gives it an advantage over loblolly where fire protection is poor. Of the four principal southern pines it suffers the least ice damage (Abel, 1948; Minckler, 1948)(___, ___). In the northern part of its range, at least, it stands prescribed burning after reaching 2 inches in diameter at breast height (Little, Allen, and Moore, 1948)(___).

Throughout its main range, shortleaf pine has good possibilities of fairly aggressive natural reproduction in succeeding rotations. It is particularly valuable for planting on abandoned agricultural land in the unglaciated portions of the Central States, because it survives where planted hardwoods do not and because the low density of its crowns permits desirable hardwoods to come in sooner than under many other conifers (Auten, 1945; Chapman, A. G., 1937)(___, ___).

Production of shortleaf seed, like that of loblolly, is frequently poor over large parts of the species' range (Hall, 1945; Wood, 1939)(____, ____), especially in the mountains. The cones are small, difficult to detach, and expensive to collect. In the southern part of the shortleaf range, high summer temperatures appear to hinder the normal growth of nursery stock. Rabbit injury during the first year after planting may be severe. Nantucket tip-moth damages shortleaf as badly as it does loblolly. Shortleaf is rarely affected by southern fusiform rust, but in many places is heavily infected by a closely related fungus, Cronartium cerebrum Hedge. and Long (Lamb and Sleeth, 1940)(____). Although shortleaf seedlings sprout after burning, small ones are more easily killed back by fire than are young slash and especially longleaf.

The most serious handicap from which shortleaf suffers is its extreme susceptibility to littleleaf disease (Hepting, Buchanan, and Jackson, 1945)(____). This disease may make shortleaf useless for planting throughout the Piedmont and some adjacent territory. At present it seems poor policy to plant shortleaf pine in pure stands anywhere within the range of loblolly pine.

CHOICE OF SPECIES TO PLANT

Climate and other conditions within the southern pine region vary fully as much as the characteristics of the different species.

Mean annual temperatures within the southern pine region, for example, vary from 55° to 75° F. Minimum temperatures vary even more widely, and average frost-free periods range from 200 days or less (Missouri, northern Mississippi, Maryland) to more than 320 days per year (Florida)(U.S. Dept. Agr. 1941)(____).

In a large area in northern Florida, southern Georgia, and southeastern Alabama (figure 4), rainfall between November 1 and April 30 averages about 7 to 11 inches less than it does in Louisiana, Mississippi, and central Alabama (Ward, 1925)(____).

Figure 4.--Approximate locations of some plantation and nursery hazards. Compiled from (Anthony, 1928; Hepting, Buchanan, and Jackson, 1945; Lamb and Sleeth, 1940; Siggers, 1934; Siggers, 1944; Siggers, 1946; Siggers and Lindgren, 1947; Smith, B. F., 1932; Smith, M. R., 1939; Ward, 1925)(_____, _____, _____, _____, _____, _____, _____) and other sources.

Brown spot needle disease generally affects longleaf pine more seriously from southwestern Alabama westward than it does farther east. Southern fusiform rust is most serious at and near the junction of the loblolly-hardwood with the longleaf-slash types east of the Mississippi River. Littleleaf disease is worst in the Piedmont. Pocket gophers do not occur between western Alabama and central Louisiana (Anthony, 1928; Crouch, 1933)(____, ____), but east and especially west of this zone success in planting may depend on systematic control of these rodents. Texas leaf-cutting ants do not occur east of central Louisiana (Smith, 1939)(____), but are a serious threat to young pine plantations in western Louisiana and eastern Texas. Figure 4 indicates the main zones of occurrence of these hazards to plantations and nurseries; the zones of others are described on pp. 374 to 404.

In many instances, species characteristics and local conditions combine to make one species preferable to any other; this is generally true, for example, of shortleaf pine in Missouri, Oklahoma, and parts of Arkansas. Frequently, however, two or even three species are more or less equally adapted to the general conditions of an area, but unequally adapted to the local site.^{3/} In such cases the planter must

^{3/} Site, as used here, means land which, because of certain characteristics it possesses, has a fairly uniform effect on the survival or growth of one of the southern pines in plantations. Throughout this bulletin, unless otherwise noted, site will be used in this sense only. Foresters cannot yet classify much of the plantable land in the South in terms of height of dominant trees at 50 years.

decide which species to plant on each individual site. This decision involves not only a knowledge of species characteristics, but also an intimate acquaintance with the soils, drainage, grass, brush, erosion, and local hazards on the individual sites themselves.

The southern pines have been planted almost entirely in pure stands, and on some hundreds of thousands of acres single-species plantations hold much promise. Other thousands of acres, however, promise only moderate success at best, or have already failed because the wrong species was chosen.

Millions of acres yet to be planted lie within the ranges of at least two southern pines, and in localities where both species have reasonably good chances of thriving, but where either may be injured, at a time and to a degree impossible to predict, by some influence or pest affecting one species more seriously than the other. Under such circumstances, and especially where sites vary greatly within short distances, planting two species in mixture ^{5/}

^{5/} Planting two species in mixture, as used here, means the inclusion of both species, usually in alternate rows or strips (groups of rows), uniformly over the planting site. Fitting individual species to different sites 1/4- or 1/2-acre up to several hundred acres in extent (Maissurow, 1939)(____), while it attains some of the objects of mixed planting, is merely an intensification of choice of species for site. It is not mixture in the present sense.

deserves consideration.

Growing species in mixed instead of in pure stands is widely recognized as a generally sound silvicultural principle, especially in connection with the control of insects and disease (Anonymous, 1932; Behre, 1932; Boyce, 1938; Curtis, 1943; Hansbrough, by Schmitz, 1936; Hartley, 1935; Heiberg, 1933; Lentz, 1948; Robinson, by Cline, 1942; Rudolf, 1937; Soc. Amer. For., N.E. Sec., Com. Silv., 1939; Stevenson and Bartoo, by Hough, 1940)(____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____). Planting southern pines in logically chosen mixtures may serve any or all of the four following specific purposes:

- 1.1. In localities where little planting has been done and where there are sites for which the best species is not yet certainly known, mixed planting tests the comparative survival, thriftiness, growth, and yields of the two or more species over a considerable percentage of the sites to be planted in the future. Such localities are still numerous in the southern pine region.
- 1.2. Regardless of which of two species is better adapted to any particular one-tenth acre of the planting area, planting the two in mixture insures a seed source of the ultimately preferable species for the natural regeneration of that one-tenth acre in the next rotation.
3. Unless both species make exactly equal height growth, the mixture to some extent insures the planted stand against stagnation if the first thinning must be postponed.

4. If judiciously chosen, the mixture helps insure the stand against serious depletion or outright destruction, especially by a single injurious influence.

Mixtures of slash and loblolly and of loblolly and shortleaf have proved promising in several widely separated parts of the southern pine region (Gibbs, 1948; Muntz, 1948; Stahelin, 1946)(____, ____, ____). In the plantation described by Muntz (Muntz, 1948) (____), loblolly, although inferior to slash in form, excelled it in growth rate except in a portion of the plantation accidentally burned at an early age; in the burned portion, the greater fire resistance of the intermingled slash appreciably reduced the damage to the burned stand. An adverse effect of mixing slash with loblolly has, however, been reported from the zone of frequent, severe ice damage near State College, Mississippi. Here the presence of slash in a mixed plantation greatly increased the ice damage to loblolly, as compared to that suffered by loblolly in pure stands (Abel, 1948)(____).

Specialists disagree about the desirability of planting longleaf in mixture. Some regard early prescribed burning, especially for brown-spot control (p. 399), as essential to successful planting of longleaf, and consider such prescribed burning of slash-longleaf mixtures impossible on a large scale without too great rust infection (p. 395) or outright killing of the slash. They argue that much of the longleaf type is too far outside the natural range of slash to permit safe planting of slash; that many longleaf sites within the range of slash are not suited to slash; that in alternate-row mixtures slash will suppress longleaf; and that even in 3-row or 5-row mixtures with longleaf, the slash will develop so many limby trees in the border rows as to be unprofitable. They advocate very intensive assignment of slash and longleaf to different sites within the same small area, but not mixture on the same site.

Much of the foregoing is conceded, particularly that there are some sites on which only longleaf and others on which only slash should be planted, and that longleaf should be planted in mixture with other species only in alternate strips at least 3 and not more than 10 rows wide.^{6/}

^{6/} It has been suggested that a checkerboard pattern of two species, in squares of 25 trees each, makes a better mixture. But if planted by hand, this mixture decreases labor efficiency about 20 percent (Minckler, 1944)(___), and it is almost impossible to plant by machine. Mixing two species in alternate strips costs little if any more than planting in pure stands.

For the reasons given below, however, slash-longleaf mixtures may be highly advantageous in many localities within and close to the natural range of slash pine, and particularly outside the zones of worst chronic brown-spot and southern fusiform-rust infection (fig. 4) but where the rust is still a serious threat to slash pine.

Longleaf pine is resistant or practically immune to the ills that affect slash pine, and slash to those that affect longleaf. In the localities described above, uncontrolled fires, hog damage, rabbit damage, brown spot, southern fusiform rust, and perhaps ice storms may affect part or all of any plantation. Neither the locality, nor the severity, nor the year in which the injury may occur, can be predicted; hence it is hard to justify much expenditure for protection other than the usual fire-control system and fences. At the same time, either longleaf or mixed longleaf-slash plantations in these localities, if they require prescribed burning at all, are less likely to require it early than are plantations in the worst brown-spot zones-- and slash pine soon develops enough fire resistance to stand prescribed burning (Lemon, 1946; Simerly, 1936; Squires, 1947)(__, __, __). Under the circumstances, a mixture of longleaf and slash seems cheap enough insurance to deserve a more thorough trial than it has received.

The results of experimental mixtures of slash and longleaf on the J. K. Johnson Tract (Louisiana) and the Harrison Experimental Forest (Mississippi) 7/ support this view. In these experiments,

7/ The experimental planting areas are described on pp. 502 to 507.

longleaf and slash planted in equal mixture were protected against hogs but burned severely (to simulate accidental or incendiary fires) in either the first, second, third, or fourth winter after planting, or were kept unburned but were exposed to hogs. The results showed that under like treatments, pure slash pine plantations would have been destroyed by fire in any of the first three winters, and pure longleaf by hogs in any of the four years. In the experimental mixtures tested, neither unrestricted hogs nor fire in any of the four winters killed enough of the mixed stand to leave the site seriously understocked.

It is recommended, therefore, that southern pine be planted in pure stands wherever species-characteristics and local hazards and sites make one species indubitably superior to any other. Where circumstances make local hazards highly unpredictable, and especially if there is also much question as to which of two species is better adapted to many different local sites, it is recommended that the two species that seem most suitable be planted in mixture, preferably in strips at least 3 but not more than 10 rows wide.

GEOGRAPHIC SOURCE OF SEED

Choosing seed from the wrong geographic source, even though it is of the right species for the planting site, may result in plantation failure (Bates and Rudolf, 1938; Munger, 1947; Rudolf, 1937)(____, ____, ____). Correct choice of seed source may therefore affect yields and profits more than choice of species for site. It is much more important than optimum spacing, high initial survival, or intensive early care of the plantation. Spacing, survival, and care affect the yield of the original plantation only, but source of seed affects the health and productivity both of the plantations and of all succeeding generations reproduced naturally from the planted trees.

This importance of geographic source of seed results from the occurrence, within an individual tree species, of distinct geographic races associated with definite climatic zones or other geographical units. Such races are particularly likely to exist in a species having a wide geographical range. The extensive literature on this subject has been summarized and cited in several readily available publications (Baldwin, 1942; Schreiner, 1938; Wakeley, 1944)(____, ____, ____). Distinct geographic races exist within several American species. The economic importance of geographic races has been recognized for about 75 years (Baldwin and Shirley, 1936)(____), and has been demonstrated in such important species as Douglas-fir, ponderosa pine, and red pine (Munger, 1947; Munger and Morris, 1936; Rudolf, Proceedings, 1948; Rudolf, 296, 1948; Weidman, 1939)(____, ____, ____, ____).

An experimental plantation established at Bogalusa, Louisiana,^{8/}

^{8/} The planting area is described on pp. 502 to 504.

in 1926-1927 has shown that distinct and economically important geographic races exist even within the southern half of the range of loblolly pine (Wakeley, 1944)(____). Figure 5 shows the relative heights and pulpwood yields, at 22 years, of stocks from the 4 geographic sources included in the study. Table 2 summarizes the results; most of the differences shown in this table, except in survival, are significant or very significant.^{9/} Stock from seed collected within 50

^{9/} Throughout this bulletin the terms very significant, significant, and not significant are used in their statistical sense only. They indicate, respectively, odds of less than 1 in 100, less than 1 in 20, and more than 1 in 20 that the differences described are attributable to chance rather than to the experimental treatment--in the present example, the geographic source of seed.

miles of the planting site produced 1.9 to 2.7 times as much merchantable pulpwood in 22 years as did stock from seed collected 350 to 450 miles from the planting site. The potential growth lost by using the Arkansas seed instead of the local Louisiana seed was 1.2 cords per acre per year.

Figure 5.--Effect of geographic source of loblolly pine seed on A, height of trees, and B, total merchantable pulpwood produced on 1/8 acre, 22 years after planting at Bogalusa, Louisiana. Seed sources in both pictures, from left to right, Louisiana (local), Texas, Georgia, and Arkansas.

Table 2.--Growth and development of loblolly pine, by geographic sources of seed, 15 and 22 years after planting at Bogalusa ^{1/}, Louisiana

Variable measured	Unit	At 15 years: seed from--				At 22 years: seed from--			
		Louis-	Texas	Geor-	Arkan-	Louis-	Texas	Geor-	Arkan-
		iana ^{2/}	3/	gia ^{4/}	sas ^{5/}	iana ^{2/}	3/	gia ^{4/}	sas ^{5/}
Survival	Percent	85	87	85	89	82	83	77	84
Average height	Feet	32	29	26	25	46	41	38	36
Average diameter breast high (4½ feet above ground)	Inches	5.0	4.2	4.0	3.8	6.7	5.2	5.2	4.7
Rough wood per acre (trees 4 inches and up)	Cords	14.2	8.8	6.5	6.3	41.8	22.7	17.7	15.4
Peeled wood per acre (trees 2 inches and up)	Cubic feet	1,346	849	689	614	3,620	1,987	1,588	1,412
Living trees with trunks infected by fusiform rust	Percent	6	10	32	13	4	6	37	5

^{1/} In Washington Parish. Mean annual temperature, 68°F.; mean annual rainfall, 61 inches; average frost-free period, 255 days.

^{2/} Livingston Parish, 50 miles west-southwest of the planting site. Mean annual temperature, 68°F.; mean annual rainfall, 60 inches; average frost-free period, 260 days.

^{3/} Montgomery County, 350 miles west of the planting site. Mean annual temperature, 69°F.; mean annual rainfall, 44 inches; average frost-free period, 265 days.

^{4/} Clarke County, 450 miles east-northeast of the planting site. Mean annual temperature, 61°F.; mean annual rainfall, 50 inches; average frost-free period, 200 days.

^{5/} Howard County or nearby, 350 miles northwest of the planting site. Mean annual temperature, 60°F.; mean annual rainfall, 50 inches; average frost-free period, 220 days.

The much heavier fusiform-rust infection of the Georgia than of the Louisiana, Texas, and Arkansas stock is also noteworthy. The difference in degree of infection is associated much more clearly with the longitudes of the seed sources than with their climates. This suggests that there may be different geographic races of the rust fungus in different parts of the loblolly range, to which different races of loblolly are not equally resistant. Such races are well known among the closely related cereal rusts (Johnson and Newton, 1946)(____), and occur also among various fungi causing tree diseases (Boyce, 1938)(____). The possibility of such geographic races within the fungus causing fusiform rust is an argument against using seed from distant sources even if such sources resemble the planting site in climate.

A study in South Africa has confirmed and amplified the findings at Bogalusa. In four different South African localities, the average heights of loblolly at 9 years ranged from 34.8 to 45.5, 25.4 to 40.1, 21.1 to 37.1, and 29.9 to 39.1 feet, respectively. In each of the four localities, the relative height of the planted trees depended upon the geographic source of the seed. Average diameters breast high varied in harmony with average heights. From these results, Sherry deduces the existence of a southern, an intermediate, and a northern race of loblolly pine, occurring in north latitudes approximately 30° to 31° , 32° to 35° , and 36° to 38° , respectively. Of these, the southern race is much the best adapted to South African conditions (Sherry, 1947)(____).

The South African study showed no such variations in growth of slash pine from different United States sources as it did in growth of loblolly. General observations and preliminary tests in the United States have also shown uniformity in growth of slash pine from different sources within the United States.

In the South African study, however, slash pine from British Honduras seed grew nearly twice as fast as slash pine from Georgia seed. When grown in southern Texas, Louisiana, and Mississippi, slash pine from Cuban and from British Honduras seed has proved far less hardy than slash pine from United States seed. Evidently slash pine, the range of which extends beyond the United States, includes geographic races, as does loblolly. Furthermore, there are indications that slash pine from different geographic sources within the United States is unequally susceptible to fusiform rust infection. For these reasons, use of local seed may prove fully as necessary with slash as with loblolly pine.

Local seed may be equally necessary with longleaf and shortleaf pines, whose botanical characteristics differ from one geographic region to another (Cain and Cain, 1944; Cain and Cain, 1944)(__, __). Longleaf has shown distinct differences in root and in foliage development, and shortleaf has shown distinct differences in nursery development and in subsequent growth, all definitely associated with geographic source of seed.

The evident existence of geographic races of American forest trees led the Department of Agriculture, in 1939, to formulate the following policy concerning the use of forest tree seed (McCall, 1939)(____):

Recognizing that trees and shrubs, in common with other food and fiber plants, vary in branch habit, rate of growth, strength and stiffness of wood, resistance to cold, drought, insect attack, and disease, and in other attributes which influence their usefulness and local adaptation for forest, shelterbelt, and erosion-control use, and that such differences are largely of a genetic nature, it shall be the policy of the U. S. Department of Agriculture insofar as practicable to require for all forest, shelterbelt, and erosion-control plantings, stocks propagated from segregated strains or individual clones of proven superiority for the particular locality or objective concerned. Furthermore, since the above attributes are associated in part with the climate and to some extent with other factors of environment of the locality of origin, it shall be the policy of the U. S. Department of Agriculture:

1. To use only seed of known locality of origin and nursery stock grown from such seed.
2. To require from the vendor adequate evidence verifying place and year of origin for all lots of seed or nursery stock purchased, such as bills of lading, receipts for payments to collectors, or other evidence indicating that the seed or stock offered is of the source represented. When purchases are made from farmers or other collectors known to operate only locally, a statement capable of verification will be required as needed for proof of origin.

3. To require an accurate record of the origin of all lots of seed and nursery stock used in forest, shelterbelt, and erosion-control planting, such records to include the following minimum standard requirements to be furnished with each shipment:

- (1) Lot number
- (2) Year of seed crop
- (3) Species
- (4) Seed origin:
 - State
 - County
 - Locality
 - Range of elevation
- (5) Proof of origin

4. To use local seed from natural stands whenever available unless it has been demonstrated that seed from another specific source produces desirable plants for the locality and uses involved. Local seed means seed from an area subject to similar climatic influences and may usually be considered as that collected within 100 miles of the planting site and differing from it in elevation by less than 1,000 feet.
5. When local seed is not available, to use seed from a region having as nearly as possible the same length of growing season, the same mean temperature of the growing season, the same frequencies of summer droughts, with other similar environment so far as possible, and the same latitude.
6. To continue experimentation with indigenous and exotic species, races, and clones to determine their possible usefulness, and to delimit as early as practicable climatic zones within which seed or planting stock of species and their strains may be safely used for forest, shelterbelt, and erosion control.
7. To urge that States, counties, cities, corporations, other organizations, and individuals producing and planting trees for forest, shelterbelt, and erosion-control purposes, the expense of which is borne wholly or in part by the Federal Government, adhere to the policy herein outlined.

Until additional data make more detailed specifications possible for each of the southern pines, the Forest Tree Seed Policy just quoted should be accepted as a guide 10/ by all agencies engaged in

10/ The State of Georgia Seed Law, Act of 1941, as amplified and amended by Act of 1945, requires that longleaf, slash, loblolly, and shortleaf pine seed sold or transported for delivery within Georgia be labeled essentially in accordance with Section 3 of the U. S. Department of Agriculture Policy (Georgia State Department of Agriculture, 1946)(____). The State of Georgia Seed Law also makes further requirements concerning testing, declaration, and level of germination, licensing of vendors, and many other things. For this reason, the complete text of the Act, including the most recent amendments, should be obtained from the Commissioner of Agriculture, State of Georgia, Capitol Building, Atlanta, Georgia, before attempting to market seed in that State.

artificial reforestation in the southern pine region. The requirement, in Section 4, that local seed come from natural stands, deserves special emphasis; seed from planted stands, unless the planted trees were from local seed, may have all the undesirable characteristics of seed from a great distance (Baldwin, 1939)(____). The loblolly seed-source study at Bogalusa, already described, has shown that adhering to the 100-mile zone of Section 4 of the Policy is preferable to accepting the alternative in Section 5.

PLANTING VERSUS DIRECT SEEDING

Sowing seed directly on the planting site often seems a tempting alternative to planting seedlings. The principal inducement is the chance of avoiding the difficulties and especially the costs of producing, shipping, and planting nursery stock. Other theoretically attractive features of direct-seeding are freedom from complete dependence on nursery capacities and large planting crews; a longer season for field work; a procedure more convenient for and familiar to farmers than is forest planting; and the possibility of more normal root development of the resulting trees (McQuilkin, J. A. R., 1946) (____). From present knowledge, however, direct seeding of southern pines can be recommended only as a supplement to, not as a substitute for, the planting of nursery stock.

Repeated direct seedings of southern pines in many different localities during the past forty years have resulted in occasional success (Attridge and Liming, 1940; Liming, 1945; McLintock, 1942; Minckler and Chapman, 1948; Minckler and Downs, 1946; Muntz, 1950) (____, ____, ____, ____, ____, ____). Investigators have used the method in a number of studies to establish uniform stands over small areas (Osborne and Harper, 1937; Pessin, 1944; Wahlenberg, 1946) (____, ____, ____). A very few attempts on a commercial scale have produced good stands, some of them a hundred acres or more in area (Cossitt and Tomlinson, 1949; Hayes and Wakeley, 1929; Ross, 1942; Wallace, 1940)(____, ____, ____, ____).

Some of the good stands just mentioned, however, have required exorbitant amounts of seed, or other costly investments. One "successful" direct seeding of loblolly pine required 13.5 pounds of seed per acre; one of longleaf required 25 pounds of seed per acre; another of longleaf required 13.5 pounds of seed per acre, plus high labor costs for sowing and mulching. In Missouri (Jones, 1948)(____), out of more than nine thousand acres direct-seeded, only 462 produced acceptable stands. Workers all over the southern pine region have reported similar unreliability of the method (Anonymous, 1928; Chapman, A. G., 1940; Coulter, 1934; Cummings, 1945; McQuilkin, J. A. R., 1946; Wakeley, 1935)(____, ____, ____, ____, ____). It is noteworthy that practically all the public and private agencies that pioneered in artificial reforestation with the southern pines tried direct seeding (some of them on units of a thousand or more acres, in several seasons, and by several different methods), and that without exception these agencies have turned to planting of nursery stock as cheaper and more dependable.

Even if the seed is not destroyed, cutworms, ants, and damping-off are likely to take a heavy toll of the newly germinated seedlings (Gemmer, 1928; Liming, 1945; McQuilkin, J.A.R., 1946; Roberts, 1936; Wahlenberg, 1946; Wood, 1939)(__, __, __, __, __, __); in one instance, ants were the principal cause of first-year seedling mortality on 26,000 acres (Morris and Mills, 1948)(__). Cutworms are abundant on many areas in the southern pine region at the same time that seedlings from direct seeding are at the most vulnerable age (Craighead, 1950; Crumb, 1926)(__, __), and these and other insects appear in general to be a greater obstacle to direct seeding than is commonly realized (Fowells, 1940; Fowells-Chapman, 1940; Schopmeyer and Helmers, 1947; Smith and Aldous, 1947)(__, __, __, __).

The greatest hazard to direct seeding, however, and the hardest to predict or forestall, is drought. No matter how the site is prepared or when the seed is sown, a few dry days at any time between sowing and the good development of primary needles, or a prolonged drought at any time during the first growing season (Lane and McComb, 1948; Liming, 1945; McQuilkin, J.A.R., 1946; Smith and Aldous, 1947)(__, __, __, __) may kill most or all of the trees.

Sowing from airplanes or helicopters, although it speeds up direct seeding and reduces labor costs, leaves the seed as exposed to birds, rodents, insects, damping-off, and drought as does broadcasting by hand.

Wire cones or domes (pp. 537 to 538) effectively protect seed and seedlings in prepared spots from birds and rodents, and probably to some extent from drought. They sometimes fail, however, to protect them from insects (Gemmer, 1928)(____). They also make direct seeding nearly as expensive as planting, if not more expensive, and in this way eliminate one of the principal advantages of direct seeding.

Mulching seed in spots or furrows to prevent bird and rodent depredations is less expensive than screening, but also less effective.

Disking the site exposes rodents to their enemies and conserves moisture in case of drought, but is expensive. Burning off a heavy rough, although it reduces rodent damage, brings the seed in contact with mineral soil, and is cheaper than disking, has caused frequent heavy losses from drought and some from freezing and birds.

Repeated tests of chemical repellents have revealed none effective in preventing bird or rodent depredations on direct-seeded southern pines or (Shirley, 1937)(____) other pines. Even a successful repellent would not protect the germinating seed and young seedlings from drought.

"Pelleting" seed (Ashe, 1946; Zahn, 1945)(____, ____), which is done commercially to permit control of spacing of agricultural crop plants in the row, offers little sound theoretical promise of improving the establishment of direct-seeded southern pines. It has failed to improve results in the field with two or three southern pines in at least two different States. In a third State, pelleting by two different processes very seriously reduced both germination and subsequent growth of all four principal southern pines even under ideal conditions in the nursery.

Decision to direct-seed should be made only with full understanding that success requires seed of the very highest quality (Cossitt and Tomlinson, 1949; Gleason, 1948; Shirley, 1937)(____, ____), that positive steps must probably be taken to protect seed from birds, rodents, or both, and that drought or other causes may necessitate reseeding.

SPACING AT WHICH TO PLANT

Choice of southern pine plantation spacing depends first of all on the number of trees per acre desired at the time of the first thinning ^{12/}, and second on survival.

^{12/} Except in erosion-control plantations, in which the main purpose is to cover the ground at the earliest possible date, and timber production is secondary or impracticable. Such plantations often must be spaced more closely than those established for pulpwood and timber production.

The optimum number per acre will vary with the kind and quality of products to be grown (Bull, 1947; Curran, 1938; Koehler, 153-158, 1938; Koehler, 867-869, 1938; Muntz, So. Lbr., 1948; Paul, 1930; Paul, 1932; Paul, 1946; Stahelin, 1948; Ware and Stahelin, 1946; Ware and Stahelin, 1948)(____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____). In large-scale plantations under extensive management, the optimum number will usually be less--perhaps 400 per acre-- than in small, intensively managed plantations where it may be 700 or more. The minimum number should not be so small as to waste growing space excessively while the trees are developing to merchantable size, to cause excessive branchiness, or to make the yield from the first thinning (table 3) uneconomically light. The maximum number should never be so large as to cause stagnation of the stand (p. 416) before the trees reach merchantable size (Haasis, 1930; Muntz, So. Lbr., 1948; Stahelin, 1948; Ware and Stahelin, 1948)(____, ____, ____, ____), or to increase the cost of establishment beyond what can be repaid from the products cut.

Table 3.--Effects of spacing upon yield of pulpwood from planted loblolly, slash, and longleaf pines

Species and location	Period since planting	Spacing	Survival	Pulpwood per acre	
				Total at end of period	Removed in thinning at end of period
	Years	Feet	Percent	Std.cords of unpeeled wood ^{1/}	
<u>Loblolly:</u>					
Auburn, Alabama	14	4 by 4	70	19.0	...
(Stahelin, 1948; Ware		6 by 6	81	24.9	...
and Stahelin, 1946; Ware		8 by 8	83	22.1	...
and Stahelin, 1948)		9.6 by 9.6	88	16.7	...
(____, ____, ____)		12 by 12	86	16.1	...
		16 by 16	91	12.5	...
Bogalusa, Louisiana	15	5 by 5	86	14.8	...
		6 by 6	91	12.2	...
		8 by 8	93	10.4	...
Woodworth, Louisiana	20	4 by 4	44	27.4	10.8
(Muntz, So. Lumberman,		6 by 6	61	29.9	11.9
1948) (____)		8 by 8	78	31.0	10.7
		10 by 10	74	27.0	8.3
<u>Slash:</u>					
J. K. Johnson Tract,	12	4.3 by 4.3	53	11.9	...
Louisiana (Muntz, 1947;		5.2 by 5.2	59	10.0	...
Muntz, Note 53, 1948)		6.2 by 6.2	63	9.6	...
(____, ____)		13.1 by 13.1	66	4.1	...
Lake City, Florida	13	8 by 8	90	25.9	...
(Florida Forest and Park		10 by 10	90	19.5	...
Service, 1944) (____)		12 by 12	90	18.1	...
Tallahassee, Florida	13	8 by 8	90	34.8	...
(Florida Forest and Park		12 by 12	90	20.2	...
Service, 1944) (____)		16 by 16	90	10.8	...
Auburn Alabama	14	4 by 4	73	28.6	...
(Stahelin, 1948; Ware and		6 by 6	77	31.0	...
Stahelin, 1946; Ware and		6 by 8	84	22.9	...
Stahelin, 1948) (____, ____,		8 by 8	76	17.3	...
____)		9.6 by 9.6	79	17.5	...
		12 by 12	76	15.5	...
		16 by 16	82	10.6	...
Bogalusa, Louisiana	15	5 by 5	85	18.6	5.2
(Bull, 1947) (____)		6 by 6	91	16.2	5.6
		8 by 8	90	13.2	2.4
<u>Longleaf:</u>					
Auburn, Alabama	14	4 by 4	35	7.2	...
(Ware and Stahelin, 1946;		6 by 6	42	8.6	...
Ware and Stahelin, 1948)		8 by 8	40	3.8	...
(____, ____)		9.6 by 9.6	58	6.2	...
		12 by 12	52	4.8	...
		16 by 16	64	3.3	...
Bogalusa, Louisiana	20	6 by 6	58	13.4	...
		8 by 8	58	11.4	...
		10 by 10	69	8.9	...

^{1/} All trees 4 inches d.b.h. and larger, except in the slash pine plantations at Lake City, Tallahassee, and Bogalusa, where yields are for trees 5 inches d.b.h. or

When the number of trees desired at the time of the first thinning has been decided upon, enough more must be planted to allow for expected mortality. If about 700 trees per acre are desired, 8 by 8 foot spacing gives satisfactory results where survival is better than 95 percent, but a spacing of 6 by 6 feet or closer will be needed where survival is less than 60 percent (fig. 6 and table 4).

Figure 6.--Trees per acre at 8 initial plantation spacings and varying percentages of survival.

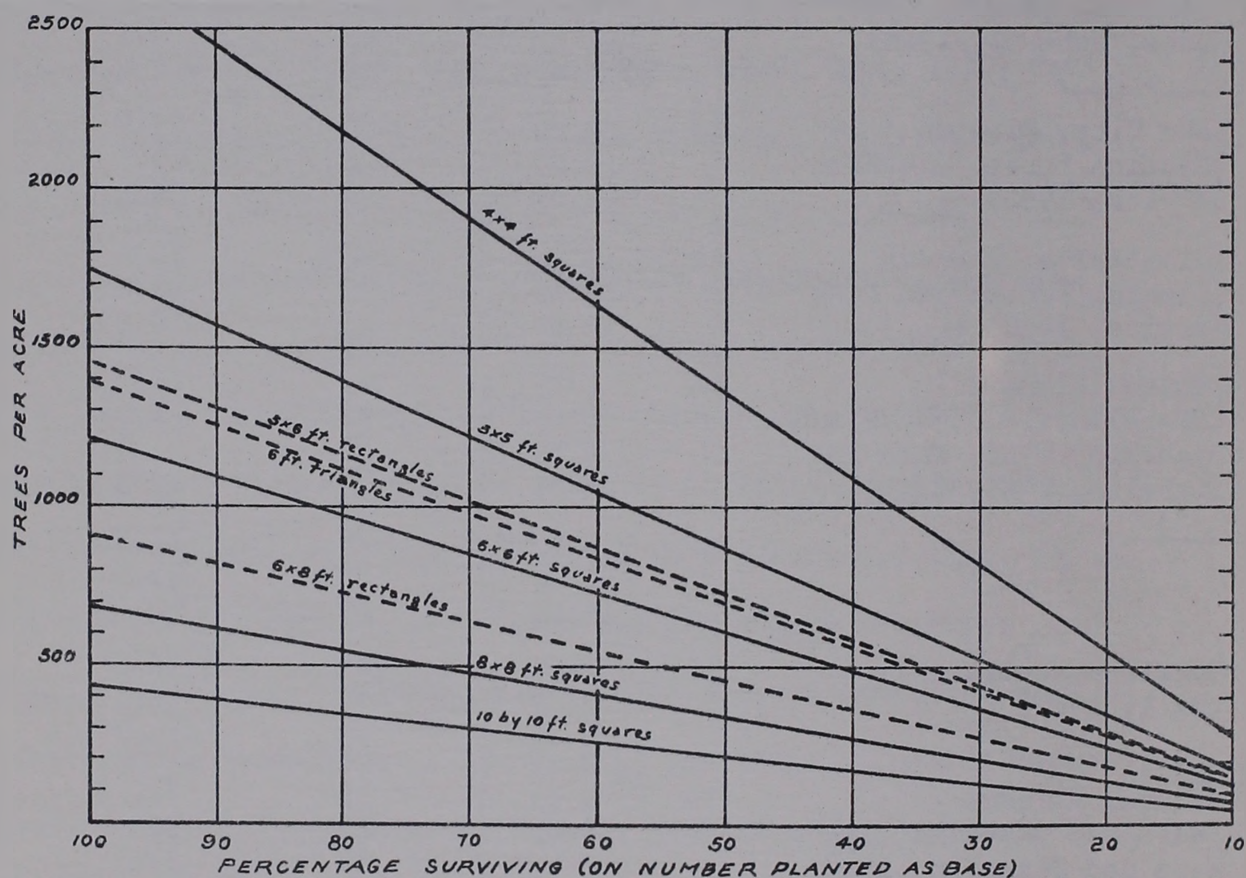


Figure 6.--Trees per acre at 8 initial plantation spacings and varying percentages of survival.

Table 4.--Trees per acre at 17 initial plantation spacings and varying percentages of survival ^{1/}

Spacing (feet)	Area per tree <u>Square feet</u>	Number of trees per acre at survival percentage of:									
		100	90	80	70	60	50	40	30	20	
TREES ARRANGED IN SQUARES											
4 by 4	16	2,722	2,450	2,178	1,905	1,633	1,361	1,089	817	544	
<u>5 by 5</u>	<u>25</u>	<u>1,742</u>	<u>1,568</u>	<u>1,394</u>	<u>1,219</u>	<u>1,045</u>	<u>871</u>	<u>697</u>	<u>523</u>	<u>348</u>	
<u>6 by 6</u>	<u>36</u>	<u>1,210</u>	<u>1,089</u>	<u>968</u>	<u>847</u>	<u>726</u>	<u>605</u>	<u>484</u>	<u>363</u>	<u>242</u>	
7 by 7	49	889	800	711	622	533	444	356	267	178	
<u>8 by 8</u>	<u>64</u>	<u>681</u>	<u>613</u>	<u>545</u>	<u>477</u>	<u>409</u>	<u>340</u>	<u>272</u>	<u>204</u>	<u>136</u>	
9 by 9	81	538	484	430	377	323	269	215	161	108	
10 by 10	100	436	392	349	305	262	218	174	131	87	
12 by 12	144	302	272	242	211	181	151	121	91	60	
TREES ARRANGED IN RECTANGLES ^{2/}											
<u>5 by 6</u>	<u>30</u>	<u>1,452</u>	<u>1,307</u>	<u>1,162</u>	<u>1,016</u>	<u>871</u>	<u>726</u>	<u>581</u>	<u>436</u>	<u>290</u>	
<u>4 by 8</u>	<u>32</u>	<u>1,361</u>	<u>1,225</u>	<u>1,089</u>	<u>953</u>	<u>817</u>	<u>680</u>	<u>544</u>	<u>408</u>	<u>272</u>	
5 by 8	40	1,089	980	871	762	653	544	436	327	218	
<u>6 by 7</u>	<u>42</u>	<u>1,037</u>	<u>933</u>	<u>830</u>	<u>726</u>	<u>622</u>	<u>518</u>	<u>415</u>	<u>311</u>	<u>207</u>	
<u>6 by 8</u>	<u>48</u>	<u>908</u>	<u>817</u>	<u>726</u>	<u>636</u>	<u>545</u>	<u>454</u>	<u>363</u>	<u>272</u>	<u>182</u>	
5 by 10	50	871	784	697	610	523	436	348	261	174	
6 by 10	60	726	653	581	508	436	363	290	218	145	
TREES ARRANGED IN EQUILATERAL TRIANGLES											
<u>3/ 6</u>	<u>31</u>	<u>1,397</u>	<u>1,257</u>	<u>1,118</u>	<u>978</u>	<u>838</u>	<u>698</u>	<u>559</u>	<u>419</u>	<u>279</u>	
<u>4/ 7</u>	<u>42</u>	<u>1,027</u>	<u>924</u>	<u>822</u>	<u>719</u>	<u>616</u>	<u>514</u>	<u>411</u>	<u>308</u>	<u>205</u>	

^{1/} Spacings well proved in practice, or theoretically desirable, are in boldfaced type.

^{2/} Wider spacing between rows than between trees in row.

^{3/} Distance between trees 6 feet; distance between rows 5.2 feet.

^{4/} Distance between trees 7 feet; distance between rows 6.1 feet.

Very often (Preston, 1943)(___), planters have assumed much higher survivals than are ordinarily attainable in their localities (Coulter, 1946; Georgia Department of Forestry, 1949)(___, ___), and have planted at spacings too wide to give satisfactory stands. This has been particularly true with longleaf pine, which suffers more mortality than other species between the first year and the age at which the crowns close (p. 11 and fig. 7), and which, because of its irregular height growth (fig. 3A), is less likely than other species to stagnate at close spacing and more likely to be limby at wide spacing (fig. 8D). Under any given set of conditions, longleaf should be spaced more closely than other species (Craib by Chapman, 1948; Ware and Stahelin, 1946; Ware and Stahelin, 1948)(___, ___, ___).

Figure 7.--Typical survival patterns of planted loblolly, slash, and longleaf pines, Bogalusa, Louisiana. The two longleaf plantations had almost identical initial survivals, but their mortality from brown spot needle disease and other causes differed conspicuously during the next 19 years.

Figure 8.--Slash pine (A and B) and longleaf pine (C and D), 14-1/2 years after planting at 4 by 4 foot (left) and 8 by 8 foot spacing at Auburn, Alabama. At 4 by 4 foot spacing the live crowns of the slash are too short and growth has stagnated; at 8 by 8 the slash, despite high survival, is somewhat limby. Because of its much better crown differentiation, the longleaf at 4 by 4 still has long live crowns and has not yet stagnated; at 8 by 8 it is excessively limby. The ground vegetation in D shows that the trees have not yet begun to use all the growing space.

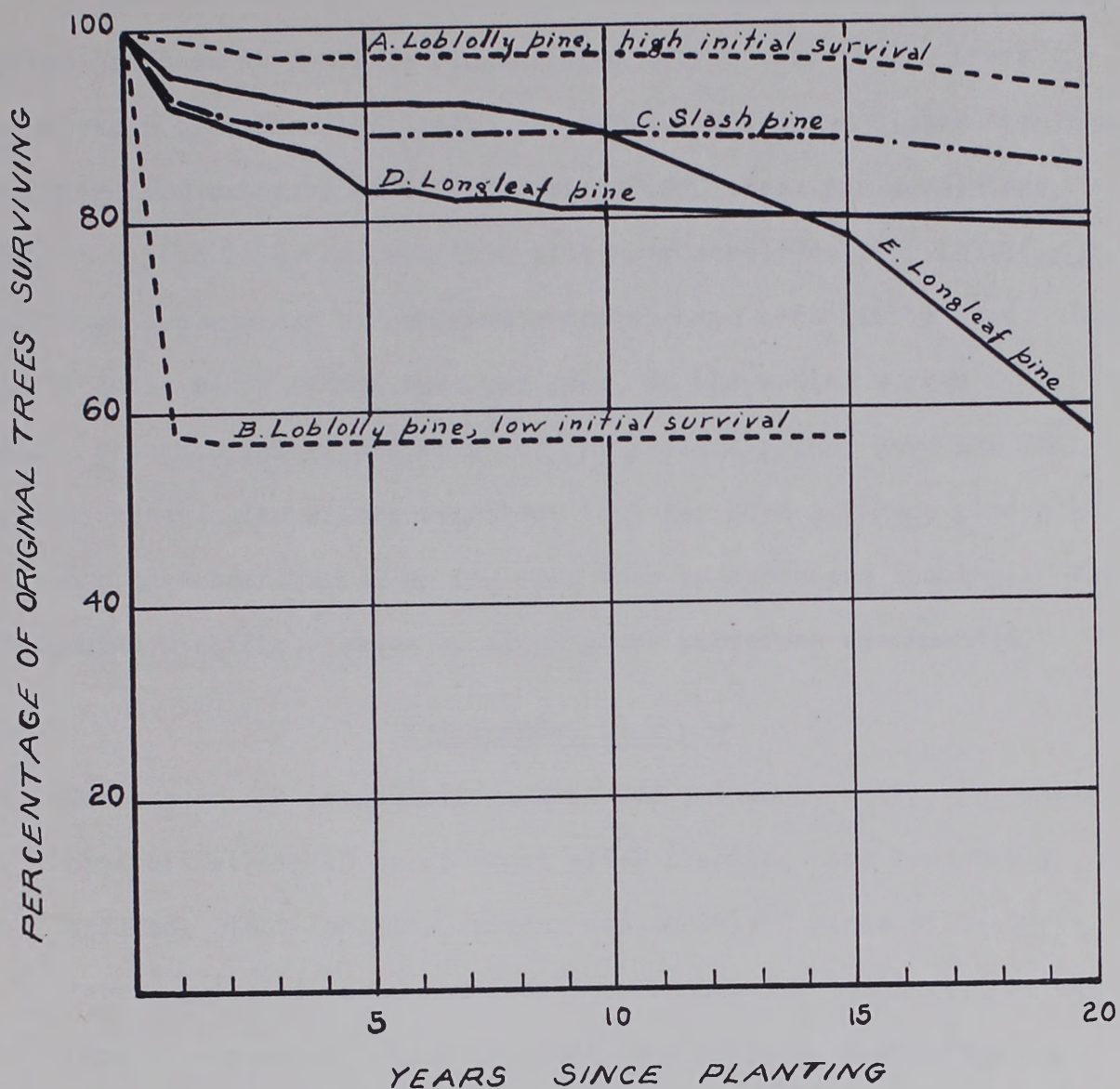


Figure 7.--Typical survival patterns of planted loblolly, slash, and longleaf pines, Bogalusa, Louisiana. The two longleaf plantations had almost identical initial survivals, but their mortality from brown spot needle disease and other causes differed conspicuously during the next 19 years.

Most industrial, farm, and Forest Service planting with southern pines has been at spacings ranging from 6 by 6 feet (1,210 trees per acre) to 8 by 8 feet (681 trees per acre). Wider and closer spacings, ranging from extremes of 2 by 2 feet (10,890 trees per acre) (Lear, 1935)(___) to 16 by 16 feet (170 trees per acre) (Coulter, 1934)(___), although recommended by numerous authors, have been little used. The 6- by 6- to 8- by 8-foot spacings have, on the whole, worked fairly well, though opinions differ as to how perfectly they have met individual needs. The writer considers that far more southern pine plantations have been marred by too wide than by too close spacings. The following specific choices of spacing are therefore recommended.

Recommended Spacings

1. Where good and accessible markets for pulpwood, posts, or smaller products within 13 to 15 years after planting seem reasonably assured, plant loblolly, slash, and shortleaf pines at 5- by 6-foot spacing on farms and 6 by 6 on industrial holdings. On either type of ownership, plant longleaf pine at 5- by 5-foot spacing.
2. Where markets for pulpwood, posts, or smaller products seem uncertain and where plantation survival is generally 80 percent or higher at 15 years, plant loblolly, slash, and shortleaf pines at slightly wider spacing, as 6 by 7 or 6 by 8 feet, but never wider than 8 by 8 feet; plant longleaf at 6 by 6 feet. If there is strong local evidence that survival is likely to be below 70 percent at 15 years, plant longleaf at 5 by 6 and other species at 6 by 6 feet, regardless of prospective outlets for products.

3. On farms on which wood from early thinnings can be used or sold for domestic fuel, plant all species at 5 by 5-foot spacing.
4. Use 4-by 4-foot spacing only in erosion-control plantations where quick, complete coverage of the ground is essential and initial mortality is likely to be high.

Following these recommendations involves, in general, somewhat closer plantation spacings than have been customary in the southern pine region.

Spacings much wider than those hitherto used in the South have been adopted in South Africa for use with exotics, including the southern pines (Craib, 1939; Craib, 1947)(____, ____), and have been cited in the American literature (Bull, Forest Farmer 1949; Craib by Chapman, 1939; Craib by Chapman, 1947)(____, ____, ____). Although these wider spacings appear attractive because of their low per-acre costs for planting stock and planting labor, and the early attainment of large diameters, they have been developed to fit climatic, soil, and economic conditions radically different from those in the South (Craib, 1939; Troup, 1932)(____, ____), and they involve heavy costs for replacement planting, repeated artificial pruning, and other plantation care. They are not recommended for commercial use in the southern pine region until the good results obtained with them in South Africa shall have been substantiated experimentally under local conditions in the South.

Arrangement of Trees in Other Than Square Spacings

The spacings so far discussed have been square or rectangular (5 by 5 to 8 by 8 feet, or 5 by 6 to 6 by 8 feet). In these spacings the distance between rows is little if any greater than the distance between trees in the row, so that each tree is about equally crowded on all sides.

When trees at a given number per acre are planted in plowed furrows or by machine, it reduces costs to increase the distance between rows and to decrease correspondingly the distance from tree to tree along the row. The widely popular 6 by 8 spacing was originally substituted for 7 by 7 spacing because it reduced the cost of plowing furrows about 12 percent, with no increase in the cost of hand planting.

Still longer, narrower rectangles, such as 5 by 10 or 4 by 12 feet, would make correspondingly greater savings in cost of machine operation. It seems likely, however, that at some point such modifications must affect form or growth unfavorably by over-crowding the trees in the row. Until experiments have disproved the likelihood of such unfavorable effects, extremes of rectangular spacing like 4 by 12 feet cannot be recommended for general use. There is little merit in the argument that such spacings admit trucks between the rows. At any commonly used square spacing it has proved practical and profitable to cut truck trails along the best routes at the time of the first thinning and to utilize the trees removed.

Planting in equilateral triangles instead of in squares or rectangles makes best use of space. Such triangular arrangement allows 15 percent more trees per acre with a given distance between trees, or 7.5 percent greater distance between trees with a given number of trees per acre, than does square spacing. Theoretically, therefore, it may serve as insurance against replanting if mortality is high, or against stagnation if mortality is low and thinning must be postponed (Baldwin and Troop, 1948)(____). Practically, however, it requires more care in alignment than is ordinarily justifiable in hand planting, and it is impossible to apply rigorously in any type of machine planting so far developed.

MEANS OF OBTAINING PLANTING STOCK

The planting stock used for the great majority of southern pines consists of bare-rooted 1-year old ("1-0") nursery-grown seedlings.

Most farmers buy such stock from large, centralized, permanent State nurseries. In all the southern States, orders for stock from the State nurseries may be placed directly with the State foresters; in some States they may be placed also through district foresters, county agricultural agents, or other designated officials. It is advantageous to both the purchaser and the State forester to have orders placed by May or earlier in the spring preceding planting.

Most Federal and State agencies and a few industrial operators grow their own nursery stock. Such planters may have to choose between establishing large, centralized nurseries or small, local ones, or between establishing permanent or temporary nurseries. Choice depends on individual circumstances, but several points should be considered, especially in deciding doubtful cases.

The planter who produces his own nursery stock has better control over the geographic source of seed used than do planters who buy stock. He also has much better control over lifting and shipping schedules. On the other hand, producing good stock in regular quantities every year requires knowledge and experience frequently not available to the small-scale planter. It also requires investments in soil and equipment which the small-scale planter may consider justified only if he is unable to buy stock elsewhere.

In general, the larger the nursery the less the cost per thousand trees for technical manpower and modern nursery equipment. This has been the principal reason for the development of a few large southern pine nurseries, usually with capacities of ten to thirty million trees a year, rather than a much larger number of smaller nurseries. It is, however, much easier to find a good nursery site with a capacity of one to five million trees a year than an equally good one with a capacity of ten to twenty million trees a year.

Although definite data are not available, it is suggested that an industrial concern with a competent forestry staff and a planting schedule of three to five million trees a year may find it more economical to grow its own nursery stock than to buy it. Under exceptionally favorable circumstances, such firms may save money by growing their own stock even for programs requiring less than half a million trees a year.

For plantations on numerous individual farms, and on certain adverse sites in some extensive planting programs, "ball-planted" natural seedlings may give better results than bare-rooted nursery stock, and at similar or lower costs (Carter and Rothery, 1940; Horton, 1936; Morriss, 1940; Morriss and Mills, 1948; Swarthout, 1941)(__, __, __, __, __)(C. H. Coulter, Florida Forest and Park Service, personal communication). The essential requirement is a supply of natural seedlings of the right size and on suitable soil within three miles of the planting site. Special tools and techniques for such planting are described on p. 349.

Natural seedlings are likely to have root systems too poorly developed (Kozlowski and Scholtes, 1948)(__) for successful bare-root planting and attempts to use them for such planting have become rare.

WHAT CONSTITUTES PLANTABLE LAND

Exactly what land to plant must be determined in the light of local circumstances--soil, erosion, markets for products, characteristics of existing brush, and opportunities for releasing trees from brush. Workable definitions of plantable land are essential in estimating requirements for planting stock. Without such definitions, also, some crews will waste stock by planting it where it cannot thrive and others will waste space by leaving favorable sites unplanted.

Abandoned fields and cut-over longleaf sites with good soil, free from brush, near good markets, in localities where planting generally succeeds, and lacking both seed trees and established seedlings, are obviously plantable. The difficulty comes in drawing the line between less favorable yet still plantable sites, and really unplantable land.

As a general guide, land may be considered unplantable for the six following reasons, alone or in combination:

1. Enough reproduction, either natural or from previous planting, to occupy the site satisfactorily.
2. Good likelihood of sufficient natural reproduction from seed trees on or next to the site, within the next one or two good seed years. (In Florida, some companies consider it more profitable to plant than to wait even 3 to 6 years for natural restocking (Coulter, 1946)(___).)

3. Remoteness from sure markets. Few tracts in the South are unplantable for this reason alone, although distance from established markets may combine with other conditions to make land unplantable or to make wide spacing advisable.
4. Soil so poor that acceptable survival cannot be attained, or that subsequent growth cannot repay the cost of planting no matter how cheap the planting or how good the initial survival. Many deep, coarse sands, some excessively wet or dry soils, and occasional rocky soils fall within this classification. So do some eroding sites on which other plants will stop erosion as effectively as pines, and at a lower cost.
5. Need for using special and excessively costly preplanting and planting techniques to insure success. This situation exists on some very brushy sites, some poorly drained sites, and on many sites on which erosion can be controlled more cheaply with other plants than with pines.
6. Conditions under which no known planting technique gives reasonable promise of success.

In deciding whether there is enough reproduction present to occupy the site satisfactorily, Region 8 of the U. S. Forest Service (U. S. Forest Service, 1939)(____) has considered land within the southern national forests as definitely plantable if it averaged fewer than 250 milacres ^{13/} per acre occupied by established seedlings,

^{13/} Thousandths of an acre; in practical reconnaissance and planting surveys, mutually exclusive squares 6.6 feet on a side.

and usually or probably plantable if it averaged 250 to 500 milacres so occupied (pp. 317 - 318). On the other hand, plantations have not been classified as failures needing replanting until mortality has left, on the average, fewer than 100 to 250 milacres per acre occupied by either natural seedlings or planted trees (p. 405).

Region 8's rules have proved practicable in large-scale planting on the southern national forests. In planting for intensive management, as on farms or close to pulp mills, land with even more than 500 occupied milacres per acre might be considered as definitely plantable.

On a vast acreage of eroding land, reasons 4 and 5 for considering land unplantable must not be applied too literally 14/.

14/ This is true also of spoils banks left from strip mining; these frequently require planting to **reduce** unsightliness or to comply with State law.

On such sites planting often is necessary and amply justified to reduce run-off and erosion, even if there is good evidence that the wood produced will not repay the costs of planting. In no extended program (Craib, 1939)(___), moreover, is it economically possible to plant only the best areas.

The general tendency to plant clear land first and leave brushy areas until later may not always be wise. If the brushy areas are much more expensive to plant, and give poorer survival and growth, planting the open areas first may, indeed, be the most profitable procedure. Experience gained on the open sites may help improve results in the brush, and the brush itself may become easier to plant as it grows older. Planting the brushy sites first may be more profitable, however, if they are potentially more productive than the open sites (Rudolf, 1937)(___), or if the presence of some brush improves survival (Nelson, 1939; Rudolf, 1937)(___, ___), or if planting becomes more difficult and expensive as the brush grows older. No general rule can be given; the best time to plant the brushy areas must be decided in the light of local circumstances.

PLANTING COSTS AND PLANTATION YIELDS

Average southern pine planting costs and plantation yields are much in demand as guides to planting policies and to plans for new planting programs. There are few situations, however, in which any such averages now available can be used effectively without considerable modification or correction.

Few complete cost figures have been published. All those so far compiled have soon been put out of date by technical advances and by changing wage scales. Growth and yield data are less subject than costs to change with passage of time, but good growth and yield data are available for plantations only up to 20 or 25 years old. Most important of all, local circumstances cause such large variations in costs, growth rates, and yields that general averages seldom indicate dependably the costs of or yields from individual plantations. For these reasons, the information that follows may be at best only rough approximations of future costs and yields, and should be scrutinized and corrected in the light of current local conditions and experience.

Over-all Costs

The most comprehensive and complete figures on the cost of planting the southern pines are those of the U. S. Forest Service for producing 196 million trees and outplanting 187 million during the period 1937-38 through 1941-42 (table 5). In addition to showing absolute costs under explicitly recorded conditions, these figures demonstrate several important relationships between seed, nursery, and field-planting costs for different southern pine species (pp. 195 to 196 311 to 313, and 370 to 372).

Table 5.--Average costs per thousand trees planted, Region 8, U. S.
Forest Service ^{1/}

Species and nursery	: Element : of : cost <u>2/</u>	Nursery season					:Weighted
		1937	1938	1939	1940	1941	: average
		<u>Dollars</u>					<u>Percent</u>

Longleaf pine:							
Ashe Nursery	Seed	1.42	1.27	0.82	0.78	1.11	17.2
	Nursery	1.65	2.43	2.31	1.92	2.83	35.7
	Planting	2.97	2.92	2.71	2.85	3.04	47.1
	Total	6.04	6.62	5.84	5.55	6.98	100.0
Stuart Nursery	Seed	1.29	1.11	1.62	.65	.87	15.7
	Nursery	2.53	2.81	2.41	2.03	3.03	35.8
	Planting	4.56	3.07	2.92	3.13	3.48	48.5
	Total	8.38	6.99	6.95	5.81	7.38	100.0
Slash pine:							
Ashe Nursery	Seed	.50	.92	1.20	.80	2.72	14.5
	Nursery	1.65	2.43	2.31	1.92	2.83	40.4
	Planting	2.35	2.49	2.52	2.49	2.69	45.1
	Total	4.50	5.84	6.03	5.21	8.24	100.0
Stuart Nursery	Seed	.46	.63	.63	.44	.57	9.1
	Nursery	2.53	2.81	2.41	2.03	3.03	43.3
	Planting	3.21	1.06	4.41	3.29	4.32	47.6
	Total	6.20	4.50	7.45	5.76	7.92	100.0
Loblolly pine:							
Ashe Nursery	Seed	1.32	...	1.21	.68	1.94	18.6
	Nursery	1.65	...	2.31	1.92	2.83	26.6
	Planting	11.49	...	4.54	4.46	3.44	54.8
	Total	14.46	...	8.06	7.06	8.21	100.0
Shortleaf pine:							
Ozark Nursery	Seed	.24	.37	.77	.21	.37	3.4
	Nursery	4.70	10.11	4.92	3.29	5.58	48.9
	Planting	6.51	6.56	4.83	4.38	3.77	47.7
	Total	11.45	17.04	10.52	7.88	9.72	100.0

^{1/} Seed and nursery costs based on 196 million trees, planting costs on 187 million trees.

^{2/} Nursery costs include lifting, grading, and packing. Planting costs include preparation of site (except fencing) and transportation and planting of stock.

The work on which these costs were based was done mostly by Civilian Conservation Corps enrollees at a computed labor charge of only \$1.50 for a 6 to 6-1/2 hour day. The balance was almost entirely by Works Progress Administration labor. All the planting was done by hand, practically all of it with planting bars. The costs shown include not only all direct labor charges, but also all shipping charges for cones, seed, and planting stock, maintenance and depreciation of all equipment and buildings, maintenance of soil fertility in nurseries, and all direct administration including technical supervision by nurserymen and the salaries of nursery shipping clerks. They exclude, however, the cost of planting reconnaissance and re-examination, most plantation fencing, and all overhead supervision.

The costs were recorded after the nurseries were well established, the initial difficulties had been largely overcome, and the principal operations (such as sowing and lifting) had been mechanized. The nurseries were producing at very nearly their rated capacity during the period in question, and were therefore as efficient, economically, as the layout would permit.

Although these costs are in terms of a thousand trees produced or planted, they are also closely equal to the U. S. Forest Service costs per acre for the period noted. Most of the planting was at 6- by 6-foot spacing, or 1,210 trees per acre, but established seedlings, large trees, or clumps of unplantable brush reduced the number of trees actually planted to about 1,000 per acre.

The costs per thousand trees varied as follows: seed, from \$0.21 to \$2.72; total nursery costs exclusive of seed, from \$1.65 to \$10.11; shipping and field planting costs, from \$1.06 to \$11.49; total costs, from \$4.50 to \$17.04. In the face of such variations within the operations of one large, stable organization with a relatively specialized form of land ownership--the southern national forests--a single, over-all average planting cost is practically meaningless. For this reason no such over-all average has been included in table 5.

Special Costs

An important point in connection with field planting costs is that it is practically always cheaper to forestall injuries (p. 374) known to threaten the planted trees than it is to lose established plantations or to replant. Reasonably good fire control, for example, is essential to success with all species, including the fire-resistant longleaf, and should be established before planting begins.

Fencing against hogs is almost invariably necessary with longleaf, and may be with slash pine where hogs eat the roots of this species also. It should be completed before planting starts. To minimize costs per acre, lumber and pulp companies and the U. S. Forest Service usually fence approximately square or roughly circular units of ten to thirty thousand acres each. Sites occupied by scattered longleaf seedlings that are already infected with brown spot often should be prescribe-burned before planting with longleaf, to delay brown-spot infection of the planted tree.

Pocket gophers and leaf cutting ants, if they exist on the planting site, should be eradicated or at least greatly reduced before planting begins. Funds should be provided for inspection after planting and for further control as needed.

The principle of forestalling predictable injuries rather than gambling upon chance escape applies to seed treatment and nursery practice as well as to field planting. It is cheaper to pay the slight extra cost of cold storage on all seed lots than to weaken or ruin even a few lots by storing them at air temperature. Longleaf stock in the nursery must almost invariably be sprayed to prevent brown-spot infection. Slash seedlings must be sprayed faithfully to prevent southern fusiform rust in any nursery subject to this disease. Where such destructive pests as cutworms, mole crickets, red spider, scale insects, or white grubs are likely to attack, it is cheaper to have the proper insecticides on hand than to be caught without them when trouble strikes.

Plantation Growth and Yields

The plantations established at Bogalusa, Louisiana, by the Great Southern Lumber Company (now owned and managed by the Gaylord Container Corporation) are the preeminent source of data on the growth and yields of extensive plantations of southern pines. Nearly 13 thousand acres of southern pines were planted at Bogalusa between 1920 and 1926. Prior to 1926, other successful plantations in the South did not total 500 acres. Representative yields from the Bogalusa plantations are as follows (Young, 1950)():

a. Eight hundred acres of direct-seeded loblolly pine averaged 21 cords per acre in 28 years, or 0.75 cord per acre per year. The best portion ran 34 cords per acre, or 1.21 cords per acre per year.

b. Twelve hundred acres of planted loblolly pine (wild stock) averaged 22.5 cords per acre in 26 years (including 2.7 cords removed in thinning at 18 years), or 0.86 cord per acre per year.

c. Seven thousand acres of longleaf pine averaged about 10 cords per acre at 20 years, or 0.5 cord per acre per year. The best portion averaged 27.3 cords per acre at 20 years, or 1.36 cords per acre per year 15/

15/ This most successful portion of the plantation was burned over, during the second winter after planting, by a quick, hot fire which caused negligible mortality but which effectively controlled brown spot and resulted in early height growth. Over large portions of the burned area, survival 18 years after planting was still 85 to 95 percent.

d. Six thousand five hundred acres of slash pine averaged 37.7 cords per acre at 24 years, or 1.57 cords per acre per year. First thinnings, begun at 24 years, yielded approximately 10 cords per acre.

Figure 9 shows a portion of the slash pine described in d as it looked 20 years after planting. Such stands, representative of much of the slash pine, the better loblolly, and a little of the best longleaf planted at Bogalusa, may be thinned profitably for pulpwood from the thirteenth to the fifteenth year onward (the twentieth with longleaf), leaving ample trees for future cuts of pulpwood, poles, sawlogs, and piling .

Figure 9.--Slash pine 20 years after planting on cut-over longleaf land at Bogalusa, Louisiana. The dominant and codominant trees compare favorably in size with the poles carrying the Rural Electrification Administration power line along the road.

Many faster growth rates and higher yields than those just cited have been reported. Loblolly and slash pines have grown at average rates of 1.4 to 2.3 cords per acre per year for the first 13 to 22 years after planting. Shortleaf pine in southern Illinois has averaged 1.0 cord per acre per year the first 13 years after planting. Loblolly in New Jersey has yielded 5,000 board feet per acre 20 years after planting. Thirteen-year-old slash pine planted at 12-by 18-foot spacing in Florida has produced 21 barrels of gum per thousand faces and grossed \$1,360 worth of gum in one year from half the trees on 40 acres. (Anonymous, 1928; Anonymous, 1946; Anonymous, 1946; Coulter, 1946; Gaines, 1945; Howell, 1948; Lane and Fasshacht, 1948)(____, ____, ____, ____, ____, ____, ____)

For two reasons, however, reports like these should be discounted somewhat in estimating probable plantation yields. First, such reports are almost invariably based on small plantations or plots of exceptionally full, uniform stocking. Second, there is a strong tendency for only maximum or near-maximum yields to find their way into print. None of the yields cited in the preceding paragraph, for example, is less than 1.0 cord per acre per year. By contrast, yields of equally old 6- by 6- to 8- by 8- foot plantations tabulated in other sections of this bulletin range downward from comparable levels to 0.3 cord per acre per year for loblolly pine, 0.7 cord for slash, and 0.3 cord for longleaf.

Any more precise estimate of future growth than can be made from the figures already given here must depend, for some time to come, on data from plantations in the vicinity of the planting sites and on data from natural stands on comparable sites nearby 16/.

16/ Planters sometimes misjudge the rate of growth of their longleaf plantations, as compared to that of natural stands, because they count age from known dates of planting or of nursery sowing, and forget that age of natural longleaf stands is determined, by convention, from stump counts plus 5 years or from age at breast height (4 1/2 feet above the ground) plus 7 years. Provided the seedlings are thrifty and have started active height growth, the planter need not be unduly alarmed if his longleaf plantation fails to average breast height 6 years after planting and 7 from seed. If the truth were known, the natural stand probably also failed to average breast height in 7 years.

In attempting such improved estimates, it must be remembered that:

(a) planting a species on a site to which it is ill adapted may seriously reduce survival and is almost certain to reduce growth and yields; (b) using planting stock of unsuitable geographic race may and in specific cases has reduced yield, sometimes to less than half (table 2 and fig. 5); and (c) some planting sites, such as badly eroded old fields, are poorer than any on which natural reproduction takes place. With these exceptions, there is no good evidence and no logical reason for supposing that stands established artificially will differ much from natural stands in rate of growth.

RECORDS AND LOCAL TESTS

Costs can be reduced and results improved by assembling and using reliable local information on seed, nursery, and planting conditions. Such information is invariably needed to help fit general practices to local needs. Part of it can be derived from routine operations. Part, however, ordinarily will require simple but systematic tests of contrasting treatments. Sound policy must recognize this and provide for accurate systems of record-keeping and testing.

Records

A vast quantity of local information becomes available in the ordinary course of work. Examples are rates of cone collection; yields of seed under current conditions and practices; time, labor, machine operation, and materials needed for various nursery jobs; stands of living and of plantable nursery seedlings from sowings at various dates and at various rates; rates of planting on various sites; dates of occurrence of common plantation injuries; and the effects of local climatic peculiarities on seed collection, nursery practice, and planting. Systematically compiling information of this sort at the time it becomes available should be recognized parts of the extractory operator's and nurseryman's jobs, and of the planting supervisor's job in any extensive planting program. The records should be strictly limited, however, to those that promise dividends in the form of more effective practices. No record should be kept unless its future use is clearly foreseen.

The absolute minimum record for each lot of seed and of nursery stock and for each plantation (pp.24 to 31) is the State and county 17/

17/ For legal requirements concerning record of origin of seed sold in Georgia, see footnote 10, p. 31 .

(or National Forest Ranger District) of seed origin. Over-all planting costs are a minimum requirement for planting records wherever it is desired to calculate profits from plantations. It is believed that in the great majority of cases something between the least and the most detailed records suggested on pp. 202, 313 to 314, and 372 will result in the greatest technical and economic benefits for the effort involved. Further suggestions concerning records are given in the literature (Lawrence, Lawrence, and Seim, 1947; Rudolf and Gevorkiantz, 1933)(__, __).

Local Tests

Small advance tests of proposed new treatments often point the way to improved results and sometimes prevent serious trouble.

Large-scale applications of locally untried seed, nursery, and plantation treatments are risky. They should be avoided wherever possible. When they do have to be applied, the minimum precaution is to put in at least one contrasting treatment on a few small samples of the seed or seedlings given the large-scale treatment.

For example, a nurseryman may use a new and untried fertilizer over an entire nursery and lose the whole seedling crop. Without check plots, he has no way of telling whether the failure resulted from the new fertilizer or from some other influence. A soils specialist or plant pathologist may be equally unable to solve the problem unless he can examine some specimens grown in the same nursery in the same year, but with some contrasting fertilizer (Davis, Wright, and Hartley, 1942)(____). Depending on circumstances, the treatment applied on the check plots may be the one regularly used before or an alternative. The essential thing is that the test involve a genuine and logical contrast to the new large-scale treatment.

The usefulness of local tests extends to practically all phases of seed handling, nursery, and planting technique. If small test lots of seed or stock are treated by one or more contrasting methods, contrasts in results almost invariably develop, and very often show the source of any trouble that may have arisen, or lead to improved results.

Examples illustrating possible combinations of contrasting test treatments and locally unproved large-scale treatments are: When a new cone kiln is installed, a few test lots of seed should be extracted in the old kiln, or at air temperature, to make sure the new kiln is not reducing the quality of the seed. When a new dewinger is installed, a few test lots of seed should be dewinged with the old dewinger or by hand. New methods of seed storage or of pregermination treatment should be checked against test lots of seed differently stored or pretreated. Drastic changes in nursery sowing date, seed-bed covers, fertilization, chemical weeding, spraying for insects or disease, machine lifting, packing and stock storage, and changes in planting site preparation and planting technique should be checked against methods formerly effective or at least against alternative new methods.

Such tests should be applied to several small lots of seed or to several widely separated small plots in the nursery or plantation, both to insure against accidents and to average out variations in seed, in soil, and the like. Preferably, the tests should be repeated for at least two successive years, to make sure that the treatment finally adopted is effective despite differences in weather, insects, or diseases from year to year. Results of both the small-scale tests and the large-scale treatments should be carefully recorded to make the information available for future use.

SAFETY

Seed, nursery, and planting operations involve the risks associated with trucks, tractors, and farm machinery, plus some special hazards of their own. Special hazards include falling, or being struck by falling objects (especially cone hooks) while climbing for cones; fire in seed-extracting plants using artificial heat; inhaled dust and dust explosions in seed-cleaning plants; poisoning by rodent poisons, insecticides, and fungicides; explosions of certain fumigant insecticides and fungicides; injury to the hands from moving parts of machinery, especially mechanical grading tables with revolving blades to prune seedling roots; cutting of the feet with planting bars; falls, blows from bent brush or flying objects, or injuries to the hands, while operating planting machines; and burns during preparation of planting sites or prescribed burning of longleaf plantations.

Sound policy and the sheer cost of accidents require constant effort to eliminate hazardous processes, to design machinery and equipment for greater safety, to train foremen and workmen in safe methods, and to enforce safety regulations. Smoking should be banned in cone sheds, seed-extracting plants, seed-cleaning rooms, and during the use of inflammable or explosive fumigants such as carbon disulfide. The utmost care (pp.508 to 509) must be exercised in using any poison, caustic, or acid. Any carelessness or horse-play with edged tools, including planting bars, should be rigorously discouraged.

Foremen should be required and crewmen should be encouraged to qualify in first aid. This training develops safe working habits, and, if an accident occurs, one man trained in first aid may prevent much suffering, or even a death, among any crew of which he is a member.

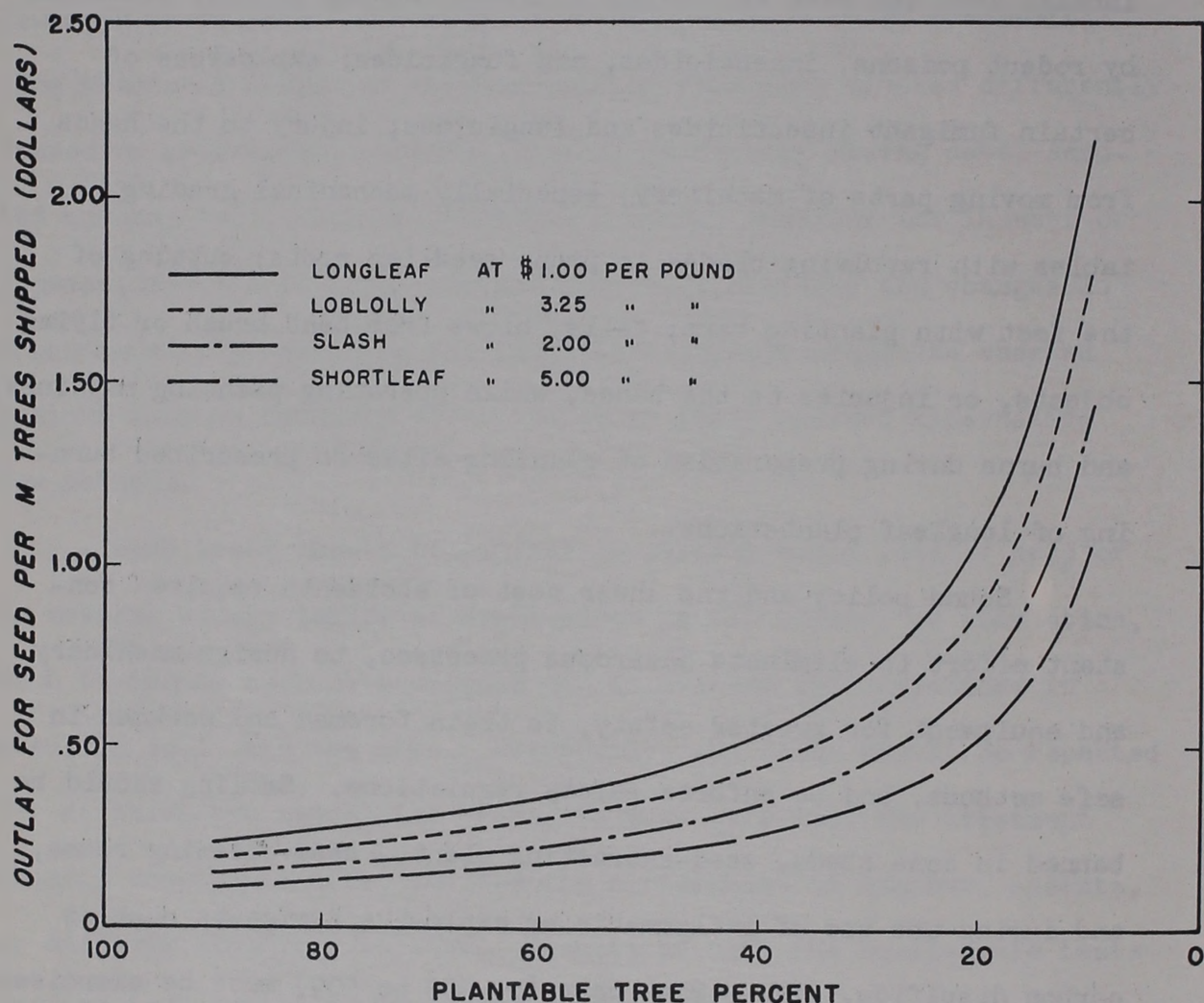


Figure 10.--Effect of plantable tree percent (that is, number of plantable seedlings obtained per 100 seeds sown) upon outlay for seed per thousand trees shipped. Shown for seed lots at representative prices and average numbers (p. 501) of seeds per pound.

SEED

Seed affects many details of southern pine planting not discussed in connection with policy. Characteristics inherent in the seed or acquired during collection and storage govern several key phases of nursery practice. The germination temperatures required, for example, determine the feasible and optimum sowing seasons for each species. Within species, the germinability of an individual seed lot principally determines the correct nursery sowing rate. Any treatment of the seed that reduces germination percent increases the cost per thousand seedlings produced. When the number of plantable seedlings obtained per hundred seeds falls very low, seedling cost sky-rockets because of excessive outlay for seed (fig. 10), and correspondingly increases the total cost of planting.

Figure 10.--Effect of plantable tree percent (that is, number of plantable seedlings obtained per 100 seeds sown) upon outlay for seed per thousand trees shipped. Shown for seed lots at representative prices and average numbers (p.501) of seeds per pound.

Seed Development

Southern pine seed takes two growing seasons to mature. In the Gulf States, slash pine usually pollinates in late January or early February, longleaf and loblolly in March, and shortleaf in April, but in longleaf pine (Mathews, 1932)(___), and presumably in the other southern pines also (Stockwell, 1939)(___), fertilization does not take place until May of the second spring. Adverse influences during the 14 months or so after pollination may easily prevent fertilization and setting of the seed.

After successful setting of even a few seeds per cone, the cones enlarge rapidly. They reach full size early in their second summer. Throughout the summer the cone tissues remain alive, transmitting water and nutrients from the tree to the developing seeds. During this period the specific gravity of the cones remains greater than 1.0.

As the second fall approaches, but before the cones become mature enough to open, the seeds become mature enough to germinate (unpublished data 18/). Next, the cone tissues begin to die. Water

18/ Unless otherwise specifically noted, unpublished data referred to throughout this bulletin are from the Southern Forest Experiment Station.

from the tree no longer replaces all that lost from the surfaces of the cones, and the specific gravity of the cones accordingly begins to decrease. By the time the specific gravity has dropped to 0.89, the cones are still closed but have matured enough to open if picked and dried. Cones on the tree usually open at a specific gravity of about 0.70, shedding their seeds in the fall or winter at dates depending on species, location, and weather.

Among the four principal southern pines, the first seed may be shed only 20 or 21 months after pollination (slash pine); the last, in extreme cases (loblolly pine)(MacKinney and Korstian, 1938)(___), 26 to 27 months after pollination and 8 or 9 months after cones and seed have matured.

Pollination of pines is entirely by wind. Single pollen grains are undoubtedly blown many miles, but there is small chance of such individual grains reaching "cone flowers" (female strobili). For pollination to be assured, a tree must be literally deluged with pollen during the few days in which the cone flowers are open to receive it.

In longleaf pine, and apparently in other southern pines, the pollen of any particular tree is likely to mature and be shed before the cone flowers on the same tree are ripe to receive it. Wherever this occurs it reduces or prevents self-pollination and increases the likelihood of cross pollination. Cross pollination between trees of the same southern pine species may be the general rule, as it seems to be with some other conifers (Allen, 1942; Allen, 1942; Hummel by Roeser, 1930)(____, ____, ____). Cross-pollination within species probably has a highly desirable effect on the vigor and adaptability of the resulting seedlings (Johnson, 1945)(____), but makes impossible the complete control of male parentage except by laborious artificial pollination. Some control of male parentage, however, is possible by collecting cones from stands which, either naturally or as a result of systematic cutting, contain only superior trees (Lindquist, 1948; Minckler, 1942)(____, ____).

With one exception, hybrids among the southern pines occur rarely, if at all. Longleaf and loblolly, the only two of the four principal species which pollinate simultaneously, frequently cross naturally to form the hybrid Sonderegger pine (Pinus sondereggeri H. H. Chapman). The long-stemmed seedlings which distinguish this hybrid have appeared in nursery beds sown with longleaf pine seed from practically every State in which longleaf grows in mixture with loblolly pine.

During the two seasons of its development, any seed crop in a southern pine stand may be reduced or destroyed by various influences. Flower buds may fail to form for any of several reasons not fully understood. Unseasonable cold may destroy the flowers. Rain may interfere with pollination. Insofar as cross pollination is the rule, individual trees may yield few seeds per cone because too few neighboring trees shed pollen at the right time. Though pollination may be sufficient, fertilization may not take place. Insect attacks either the first winter or the second fall (in longleaf pine, by moths of the genus Dioryctria especially) have at one time or another reduced or destroyed the seed crops in many localities. There have been fairly clear cases of destruction of crops by drought--for example, shortleaf pine in Arkansas in 1936. These hazards combine to cause great fluctuations in seed production from place to place and year to year, and must be allowed for in planning collection or purchase of seed and in arranging for seed storage.

SEED PRODUCTION AND YIELDS

Frequency and Extent of Seed Crops ^{19/}

^{19/} Data on seed crops have been assembled from more than 4,900 separate reports on the cone crops of southern pines from Maryland to Texas during 1931 to 1941, inclusive; from records of large-scale collections by the U. S. Forest Service in seven States; and from published reports of other large-scale collections and of numerous silvicultural investigations.

There are occasional years of simultaneous heavy seed production by all species throughout most of the southern pine region. Tradition has it that 1913 and 1920 were such years, and the good general crop of 1935 is a matter of record. There also are years of widespread failure, like 1925 and 1945.

Such general bumper crops and failures recur in no predictable pattern. Moreover, they are rarely universal; Hall (1945)(___), for example, records an "enormous" crop of loblolly and shortleaf seed in southern Arkansas in 1925. For these and other reasons (p. 24), local seed crops of individual species are of more practical interest than general bumper crops or failures. This is particularly true because the average seed production of loblolly pine, and apparently that of longleaf and shortleaf pines also, varies more from place to place than from year to year.

Loblolly pine is only a moderately regular seed producer. It seeds most abundantly near the Atlantic and Gulf Coasts; inland, it bears seed far less abundantly than has been commonly supposed (McQuilkin, 1940; Wakeley, 1947)(____, ____). In east central Alabama it produced little or no seed during the 6-year period 1940-1945; in southern Arkansas (Hall, 1945)(____) there were no heavy crops in the 13 years between 1925 and 1939; throughout most of the Lower South, loblolly seed is harder to get than that of either slash or longleaf.

Slash pine is in general a good but irregular seed producer. Because of its narrower geographic range, slash is perhaps more liable to complete crop failures (as in 1925, 1939, and 1945) than the other principal southern pines.

Although extremely variable from year to year and place to place, the seed production of longleaf pine is better than has generally been assumed. In the Gulf States alone, the U. S. Forest Service succeeded in collecting 10,000 to 85,000 bushels of longleaf pine cones each year from 1934 through 1940, and nearly 10,000 bushels even in the poor seed years of 1941 and 1945.

The seed-producing capacity of shortleaf pine, like that of loblolly, seems to have been greatly over-rated. Shortleaf is an infrequent seeder practically everywhere, and seems especially poor along the western and northern borders of its range and in the Ouachita and Ozark Mountains of Arkansas (Hall, 1945; Liming, 1945; McQuilkin, 1940; Wood, 1939)(____, ____, ____, ____).

Because of these facts, specific local crops cannot be predicted reliably from general information. Most collections must therefore be planned and carried out on the basis of field estimates (p. 79) of the cones about to mature in the localities from which seed is desired, and definite provision must be made to collect surplus seed from good crops and to store it effectively (p. 126).

Tree Characteristics Affecting Seed Production

As a rough guide in planning collections, heavy seed production should not be expected from trees smaller than 10 or 11 inches d.b.h. (Barrett, 1940; Downs, 1947; Liming, 1945; McQuilkin, 1940; Wahlenberg, 1946; Wakeley, 1947)(____, ____, ____, ____, ____, ____). Trees as small as 6 inches d.b.h., however, often bear cones in commercial quantities, and, other things being equal, the smaller the tree the cheaper the cones are to collect.

Southern pine cones need never be rejected merely because of the age of the tree (Minckler, 1939)(____). Loblolly and slash pines 7 years old, shortleaf 9 years old, and longleaf 15 years old, have all produced fair to high percentages of viable seed (Weddell, "seed", 1935; Weddell, 1939)(____, ____, and unpublished data). Longleaf seed has been collected commercially from 20-year-old trees, and loblolly, slash, and shortleaf seed from trees only 12 to 16 years old. At the opposite extreme, excellent seed has been collected from shortleaf trees 280 years old (Mattoon, 1915)(____) and longleaf 350 years old.

Within any age or size class, southern pines produce more seed if they are dominant, widely spaced, or open grown, provided always that they receive abundant pollen from other trees. (Inadequate pollination is thought to account for the frequently poor seed production of isolated trees.) Dense stands, especially if young or with very uniform crown canopies, usually have little seed. Cone crop estimates and other studies (Lodewick, 1930)(____) suggest strongly that southern pines, like other timber and game-food species (Hummel by Roeser, 1930; Wilde, game food, 1946)(____, ____), yield cones and seed at the cost of some loss in wood production, and bear seed most frequently and abundantly when growing on the more fertile sites. Many individual southern pine trees, however, are consistently good or consistently poor seeders, almost regardless of size, site, or season (Downs, 1947; Perry and Coover, 1933)(____, ____). Possibly the explanation lies in their own dates of pollination in relation to those of neighboring trees.

Yields Per Cone and Per Bushel

In round numbers, unopened longleaf cones run 100 to the bushel, slash 200, loblolly 500, and shortleaf 2,000.

In good seed years, longleaf may average 50 to 60 sound seeds per cone, slash 60 to 70, loblolly 40 to 50, and shortleaf 25 to 35. These numbers may be halved in poor years. The total number of sound plus empty seeds ranges upward to about 200 per cone.

Each of the four principal species averages about 1 pound of clean seed per bushel in good seed years, about 0.5 pound per bushel in years of light to moderate crops, and 0.2 pound or less in very poor crop years. The same amount of seed almost always requires collection of more cones in poor than in average seed years.

The above averages and the extremes given on p. 501 are suitable for general planning of cone collection and seed extraction, but not for controlling large-scale operations or for computing final costs. Individual lots vary widely from the averages, especially in yields per bushel. Cones from young trees tend to average fewer to the bushel, and cones from very old trees more than the figures cited. For satisfactory control of large operations, data should be obtained by sampling the cone lots themselves.

Shortleaf seeds average about 1/8-inch wide and 1/5-inch long; longleaf, with wings reduced to stubs, average about 1/4- by 2/5-inch. Loblolly and slash seed are intermediate in size. These variations necessitate the use of different sizes of screens, seeders, and the like in extraction and sowing.

Cleaned longleaf seed with wings intact averages about 4,200 per pound; with the wings reduced, about 4,700. Cleaned and dewinged slash seed averages about 14,500 per pound, loblolly about 18,400, and shortleaf about 48,000. Young trees tend to have fewer and old trees more than the average number of seed per pound. With this exception, the sizes of seed and the weights of seed cleaned to a common standard (as 100 percent pure, 85 to 90 percent sound) are much more constant within species than are cone sizes or yields of seed per bushel of cones. The seed sizes and weights on p. 501 can therefore be used for planning almost all operations requiring such data. The chief exception is in calculating sowing rates in large nurseries, where control of seedbed density through precise sowing is especially effective in reducing costs. Here local tables of seed weights should be used or each seed lot sampled.

ESTIMATING CONE CROPS

Although preliminary choice of a seed collecting ground depends on its geographic location (p. 24) and accessibility, on available labor and land ownership, and sometimes on logging schedules, final choice always depends on the supply of cones available. Therefore quantitative estimates of the collectible cones on one or several areas usually are necessary in deciding where to collect. Without estimates, the collector may overlook a good collecting ground and waste effort on a poor one, or attempt prohibitively expensive collection; if collecting for sale, he may accept orders which he cannot get cones enough to fill. Systematic estimates of the crop are superfluous only when the cones available obviously exceed the collector's needs.

As a starting point, any cone crop estimate requires a workable definition of collectible cones as well as some idea of the number of bushels to be collected. The definition depends on the nature of the seed trees and the method of collection (p. 89). The number depends on the quantity of new seed desired for sowing, storage, or sale. If the estimate shows an unexpectedly abundant crop, it may pay to increase the quota and collect extra seed for storage. If the estimate reveals few cones, the quota may have to be reduced, even though poor crops necessitate collecting extra cones to get a given quantity of seed.

Cone crop estimates need be only close enough to show that a particular collecting ground will yield a given quota of cones, or that one will yield the quota more economically than another. The method and intensity of an estimate will depend on the abundance of cones, the quantity desired, and the estimator's skill.

When the cone crop is fair to good and the collection quota is moderate, an experienced man can verify by eye the presence of the desired quantity while traversing the collecting ground on foot or even by car. To get equally reliable results under the same conditions, an inexperienced estimator usually must stop and count the collectible cones on sample trees, and convert the numbers to bushels. In any case, it is essential to see as much of the area as possible, rather than to make an overly precise estimate of the cones at one spot.

In poor seed years, or for large collections at any time, more intensive estimates are necessary to show the most suitable collecting ground.

A moderately intensive method of estimating involves stopping at many different parts of each proposed collecting ground and recording, on an appropriate form (table 6), quantities of cones on specific acreages. If the bushels of cones observed at the various stops do not total enough to meet the quota outright, the rates in the right-hand column (preferably weighted by area) may be averaged and multiplied by the total acreage of seed-bearing stands to see whether the quota is available.

Table 6.--Simple form for cone crop estimates

Proposed	:	Bushels of col-	:	Number of	:	Rate of
collecting	:	lectible cones:	:	acres on which	:	production
grounds	:	not less than--	:	observed--	:	per acre
	:	100 : 10 : 1	:	1: 10 : 100	:	<u>at least</u>

Bushels

Bessie Tract

Stop No. 1	x	x	0.1
Stop No. 2	x	x	1.0
Stop No. 3	x	x	0.1
Etc.	- - - etc.	- - - etc.	etc.

The most intensive estimates are needed when large collections are planned and the crops are poor or spotty. Such estimates are made by counting or very carefully estimating all collectible cones on 1/5- or 1/4-acre sample plots at intervals along compass lines grid-ironing the prospective collecting grounds. (If the crop is spotty, the patches of best cone production should be mapped to guide the collecting crews.) Plot spacing is a matter of judgment. Region 8 of the Forest Service requires a minimum of one plot per 1,000 acres on units of 100,000 acres or larger (U. S. Forest Service, 1939)(____). On areas of less than 6,000 acres, a plot every 40 to 80 acres may be needed.

The probable yield of seed per bushel of cones should be checked just before or in the early stages of collection, especially if the crop is poor. With patience and a little practice it is easy to estimate the number of filled seeds per cone to the nearest 20 or closer (p. 176). The averages for 1 or 2 cones apiece from 20 to 100 trees 20/ on each area should show which collecting ground will give

20/ This method of sampling is necessary because numbers of full seeds per cone vary much more from tree to tree than from cone to cone on the same tree.

the best yield per bushel, or whether below-average yields per cone will necessitate collecting extra cones.

Forecasts of good cone crops made from counts of cone flowers or of yearling cones would often be a great help in planning seed collection and storage. Two obstacles, however, have prevented the development of such forecasts for southern pines. One is the impossibility of counting cone flowers or yearling cones accurately without climbing or felling the trees. The other is the erratic but often heavy mortality of cones during either their first or second season of development (p. 72). Reliable and useful (Allen, 1941) (___) forecasts of cone crop failures in either the coming fall or the second fall thereafter can, however, be made from observation of a shortage or the complete absence of yearling cones or cone flowers, respectively.

Data for a forecast of the next crop may be obtained most easily and effectively from samples of seed-trees (either standing or felled) during the cone-collecting season. If the number of yearling cones is not greater than the number of mature cones on the same trees, the following year's crop will almost surely be smaller than the crop being collected.

COLLECTION AND CARE OF CONES

Successful collection depends upon: (1) collecting at the right time--after the cones mature but before they start to open on the tree; (2) employing, equipping, training, and supervising adequate crews; (3) labeling the sacks of cones correctly; and (4) taking proper care of cones between collection and extraction.

Cone Maturity

Since only mature cones can open and release their seeds, everything spent collecting immature cones is a total loss. Dates of cone ripening vary so much (table 7) that a specific test for cone maturity is needed to time the beginning of collection in any one place and season. Large-scale application has proved flotation in certain oils to be a better test than cone color, appearance of seed in cut cones, or flotation of cones in water.

The dependability of the oil-flotation test results from the decrease in specific gravity which always accompanies the final maturing of cones (p. 70). Although southern pine cones picked while their specific gravity is between 1.00 and 0.89 (that is, while the cones barely float in water) may mature after picking and eventually open, it is best to wait until the specific gravity has dropped below 0.89 (table 8). The easiest way to determine whether the specific gravity of cones is above or below 0.89 is to see whether they sink or float in a liquid with that specific gravity (fig. 11). Collection should not be delayed after the cones begin to float in the appropriate liquid, because when their specific gravity drops to about 0.70 they start to open on the trees.

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Figure 11.--Longleaf pine cone floating in SAE 20 lubricating oil within 10 minutes after having been picked from the tree, and therefore mature enough to open and release its seeds when dried.

Table 7.--Usual dates of maturity, collection, and natural opening
of southern pine cones ^{1/}

Species	Maturity	Collection	Opening on trees
Slash	Sept. 1 to 10	Sept. 1 to 20	Sept. 20 to 30
Loblolly	Sept. 20 to Oct. 10	^{2/} Oct. 1 to 20	^{2/} Oct. 10 to 30
Longleaf	Oct. 1 to 20	^{2/} Oct. 1 to 20	Oct. 20 to Nov. 10
Shortleaf	Oct. 1 to 20	Oct. 11 to 30	Nov. 1

^{1/} Based largely on observations from Georgia and Florida to Texas.

^{2/} Occasionally a week to 10 days later, especially when rainy weather delays opening.

Table 8.--Relation of yield of seed per bushel of unopened longleaf and loblolly pine cones to specific gravity of cones when picked

Species, and method of extraction	: Specific gravity when picked			
	: 1/ 1.00 :	2/ 0.99 :	3/ 0.88 :	4/ 0.79
	: or more :	to 0.89 :	to 0.80 :	or less
	- - - Pounds of seed per bushel 5/ - - -			

LONGLEAF

Immediate kiln drying at 120°F. without precuring	0.0	0.0	1.2	1.7
Drying at natural air temperature	.2	.2	1.3	1.7
Kiln drying at 120°F. after 2 weeks' precuring at air temperature	.2	.3	1.2	1.9

LOBLOLLY

Immediate kiln drying at 120°F. without precuring	.0	.3	1.3	1.2
Drying at natural air temperature	.1	.6	1.3	1.4
Kiln drying at 120°F. after 2 weeks' precuring at air temperature	.1	.7	1.5	1.4

1/ Cones sank in water.

2/ Cones floated in water but sank in SAE 20 lubricating oil.

3/ Cones floated in SAE 20 oil but sank in kerosene.

4/ Cones floated in kerosene.

5/ Each value calculated from yield of 100 cones. The study included 20 longleaf and 20 loblolly trees, each of which contributed 5 cones to each 100-cone lot.

Lubricating oils of grade S.A.E. 20, if stated by their manufacturers to have specific gravities of about 0.88, may be used as test liquids, as may a mixture (Maki, 1940)(____) of 1 part of kerosene to 4 parts of raw linseed oil. Only 2 or 3 quarts of oil, a container large enough to let the cones float without touching the sides and having a cover to keep the oil from slopping out in transit, and an ice pick for fishing out cones that sink, are needed for the test.

The crop is mature enough for safe collection whenever sound, freshly picked cones from 19 _____ of 20 random sample trees will float _____ within 10 minutes after the cones

between picking and testing may enable hopelessly immature cones to float. Wormy, deformed, or otherwise visibly abnormal cones are useless for the test, as are cones from trees that have been felled for more than a few hours.

If the cone quota does not require collecting throughout the season, it is better to concentrate collection toward the end than toward the beginning. Late collection saves getting immature cones and reduces shipping weights and spoilage. At first maturity, cones weigh about 33 to 35 pounds per bushel; just before opening, about 20 to 25. The loss of 8 to 15 pounds of moisture per bushel while the cones are on the trees correspondingly reduces extracting time and costs. There is also scattered but consistent evidence (Baldwin, Hemlock 1934; Lanquist, 1946; Maki, 1940)(__, __, __) that the later seed is collected the better it germinates. Late-collected seed probably also stands storage better. The ideal time to collect small lots of cones from abundant crops is when the first cones on a few trees have just started to open; under these circumstances the oil test is unnecessary.

Details of Collection

To avoid legal difficulties, anyone collecting on land other than his own should obtain the owner's written consent before starting to collect.

Before collecting cones inside a white-fringed beetle quarantine line and shipping them across it, the collector should get clearance from the U. S. Bureau of Entomology and Plant Quarantine and the State Entomologist or Plant Board. To insure freedom from the beetles, the cones should be kept out of contact with the ground while awaiting shipment.

Collection of cones from felled trees should be confined strictly to trees cut after the cones have matured (Baldwin, 1936) (___). The risk of getting immature cones from trees cut before cone maturity is too great, even though nearly mature loblolly and shortleaf cones sometimes finish ripening on crowns on the ground. Immature slash and especially longleaf cones seldom finish ripening after logging, because most of them fall off when the crowns hit the ground.

Collectible cones are those which can be found, reached, and picked or gathered fast enough to keep labor costs within reasonable bounds. Practically all sound, unopened cones from trees felled after cone maturity are collectible. When collection is by climbing, some cones at the ends of long branches or on very large or high-crowned trees cannot be reached. Some trees bear too few accessible cones to repay the cost of climbing. Only when climbers are very expert or seed is urgently needed does it pay to climb small longleaf or slash pine trees bearing less than 20 cones apiece, or large trees bearing less than 40 or 50 within reach of 8- to 15-foot collecting poles. Somewhat larger numbers are required to justify climbing loblolly and shortleaf, because their cones are much harder to detach, especially with cone hooks or poles, and they average fewer seeds per cone.

Rejecting the smaller cones during collection is not recommended, even if it can be done without extra cost. Although seedlings from the larger seeds characteristic of the larger cones tend at first to outgrow other seedlings in the nursery, the advantage usually is temporary, and seedlings from small seeds are as likely as those from large seeds to inherit desirable hardiness, growth rate, form, and resistance to insects and disease (Champion by Hasel, 1933; Minckler, 1939; Minckler, 1942; Mitchell by Shirley, 1939; Perry and Coover, 1933; Righter, 1945; Spurr, 1944)(____, ____, ____, ____, ____, ____, ____).

On the other hand, rejecting cones from poor trees in favor of those from trees of superior form, growth rate, and resistance to insects and disease merits consideration. Many authors advocate such collection, some to the extent of establishing "seed orchards" of superior trees (Baldwin, 1936; Bates, 1928; Champion by Hasel, 1933; Lindquist, 1948; Minckler, 1939; Minckler, 1942; Rudolf, 741-743 1948; Sherry, 1947)(____, ____, ____, ____, ____, ____, ____, ____). Some improvement in the heredity of plantations from seed selected in these ways is almost certain. Whether planted pines will benefit substantially is problematical. The known reproductive processes and apparent genetical make-up of pines indicate that the benefits may be small 21/.

21/ Because pines are cross-pollinated and apparently highly heterozygous (Stockwell, 1939)(____).

There is little evidence that selecting southern pine cones from superior trees or stands measurably improves plantations. Until more evidence becomes available from experiments, it is recommended that collection from superior trees be favored to the extent possible without extra cost.

Methods and Equipment

Where fresh cones are not available from logging operations, it is necessary to climb standing trees. Collection by climbing may seriously reduce the following year's and later crops through destruction of yearling cones or breaking off of bearing twigs (Lindquist, 1948)(___). Such injuries to trees should be kept at a minimum by training and supervising the crews.

Cone hooks on light poles are essential to efficient collection from standing trees, especially longleaf and slash. They should be adapted to both pushing and pulling (fig. 12)(Toumey and Korstian, 1942, page 114)(___, page 114). On small trees many cones are most efficiently reached from the ground with 15 to 20 or even 30-foot poles. In climbing, poles about 8 feet long, with looped thongs at the handle ends, are most convenient, but a few 15-foot poles should be available for wide-crowned trees.

Figure 12, A and B.--Collecting longleaf pine cones by climbing. B shows details of S-shaped cone hook. Many cones are more easily detached by pushing (with the other side of the hook) than by pulling.

Climbing for cones is dangerous. Safety belts should be required. All climbing equipment should be of excellent quality and should be scrupulously inspected at least once a day. Foremen should rigorously discourage recklessness and horseplay. Cone hooks should never be hung on branches above the climber, lest they slip off and cut him as they fall. Cones should never be gathered from the ground while climbers are still in the tree above.

Leather or leather-palmed gloves are needed for handling loblolly, longleaf, and slash pine cones.

It is more efficient to gather cones into bushel baskets and empty the baskets into 1-bushel or 2-bushel sacks, than to gather cones directly in loose sacks. The baskets save time, permit closer inspection during gathering than do sacks, and simplify tallying the total amount collected. A portable rack on which sacks can be hung, with mouths distended, saves much time in emptying baskets into sacks.

Ordinarily, no visibly wormy cones should be gathered. They yield only one-half to one-third as much seed as sound cones, and break up into fragments almost impossible to remove from the seed.

While they are being gathered, cones should be completely freed from pine needles and grass. Such trash cannot be eliminated as cheaply at any other stage of handling. Needles especially, if run through the extractory, break into short pieces exceedingly hard to remove from the seed.

Sacks should be closed with string, not wire. Bits of cut wire mixed with the cones are a prolific source of damage to dewingers and fanning mills.

Labeling

Because of the importance of recording seed source, a stout cardboard or cloth tag showing species, place, county, State, and collection date should be attached to each sack of cones before it leaves the collecting ground. Such labeling is particularly necessary if more than one lot of each species is going to the same extractory.

Care Between Collection and Extraction

If cones are kept in sacks or in deep piles or bins for many days early in the collecting season, they are likely to mold, heat, or ferment. If they are similarly mistreated late in the season, prevention by lack of space at the start may make normal opening impossible later on, with consequent loss of seed. Cones should, therefore, not be left in sacks more than a week -- ten days at the most. Preferably they should be spread in curing sheds or on extracting racks or trays within 3 or 4 days of collection. The importance of such spreading cannot be emphasized too strongly, and the necessary space and equipment should always be provided before collection starts.

A wetting right after collection may not harm cones, but it is safer to protect them from rain. Free circulation of air through the piles or around each sack will prevent heating and reduce not only molding but also shipping weight and the length of time needed for extraction.

EXTRACTION

Since thorough drying normally suffices to open cones of the four principal southern pines, extraction is mainly a matter of reducing cone moisture content till the cones open, then shaking out the seed. The exact moisture content required for cone opening has not been worked out in detail. Combinations of temperature and relative humidity that will bring wood to 4 percent moisture content (such as have been published as guides for kiln-drying lumber) appear, however, to be generally effective with southern pine cones (Rietz, 1939, longleaf; Rietz, 1941)(____, ____). Practical means of extracting seed mechanically, without drying, such as have been reported for ponderosa pine (Miller and Lemmon, 1943)(____), have not been developed for the southern pines.

Avoiding Injuries to Cones and Seed

Consistently successful extraction requires: (a) protection of cones from rain; (b) continuous free access of air to all cones except for brief, unavoidable storage and transportation in sacks; (c) exclusion of rodents and birds; and (d) as prompt extraction of seed as the condition of the cones will permit. Without these safeguards, decreases in the quantity or quality of the seed extracted are almost inevitable.

Mold, heating, or fermentation, or pressure on the scales as they start to separate, may keep even mature cones from releasing all their seed. The first three of these forms of injury may also reduce the viability of the extracted seed.

Insects in wormy cones overlooked during collection, especially the larvae of moths (Dioryctria spp.) in longleaf cones, may continue to feed in the extractory and consume appreciable quantities of seed unless they are destroyed by prompt kiln-drying of the cones. Rodents and birds are likely to take much seed from partly opened cones if they can reach it.

High or fluctuating seed moisture content between collection and extraction or storage (even for very brief periods and especially if accompanied by exposure to moderate or high air temperature) may prevent successful storage even if it does not immediately reduce germinability (Barton, 1941; Barton, 1943; Clark, 1948)(____, ____, ____). In a test in 1941-1942, germination of longleaf seed left in well-spread cones in a standard U. S. Forest Service cone shed decreased 8 percent between January 14 and February 11, and 18 percent between January 14 and March 31, as compared with that of seed extracted January 14 and stored at 40° F.

Too slow drying in cool, shaded places appears to decrease the yield of seed from some lots of fully mature southern pine cones, as it does with ponderosa pine (Maki, 1940)(____). The remedy is increased ventilation, exposure to direct sunlight, or kiln drying.

Precuring

Cones which have been collected when nearly mature (specific gravity approximately 1.0) may be made to finish ripening after collection. Bringing such cones to complete ripeness, especially for kiln extraction, is one phase of precuring. It usually takes two weeks or a little more. It often greatly improves the yield, and probably also the quality, of seed collected early in the season. (Among the cones in the 0.99 to 0.89 specific gravity class in table 8, this type of precuring accounts for the better seed yields from treatments other than immediate kiln drying.) Precuring is best carried out by spreading the cones in layers 2 to 6 cones deep, preferably on wire screens, in the shade, and with free but not excessive air circulation. Deeper piling of immature cones, or keeping them in sacks, makes them mold, heat, or ferment and prevents final ripening. Too rapid drying in excessive drafts or in direct sunlight, or immediate kiln-drying, also prevents final ripening.

The other phase of precuring consists of temporary storage of fully mature but still fairly moist cones (specific gravity only slightly below 0.89) in layers 6 to 8 cones deep. Such precuring prevents molding and gets rid of easily removed moisture with minimum tray or floor space. It shortens the period required for later complete drying at artificial or air temperature. Although it involves rehandling, it is often essential to efficient extraction of large shipments of cones. It is, however, only a temporary expedient, good for 2 or 3 weeks at most, and not effective for complete drying at natural air temperatures.

Extractory Design and Equipment

Extractories function effectively only when designed in accordance with the weights of cones on arrival, the amounts of water to be removed, the volumes of cones both before and after drying, and the sizes of individual cones and seed.

A space 10 by 10 by 8 feet will hold about 11 tons of newly matured cones piled in bulk, and perhaps 10 tons in sacks. After they open, cones take up 2 to 3.5 times the space they occupy when closed. The writer has seen an extractory floor collapse under the weight of green cones, and roofs lifted off by drying ones, from disregard of these facts.

The amount of water to be removed--from 6 to 17 or more pounds per bushel of unopened cones--governs the heat and airflow requirements of cone kilns, and the requirements for ventilation in extraction at air temperature.

Of particular importance in designing trays, racks, cone kilns, and the general layout of extractories are the areas required to spread cones in single layers and the clearances required between trays or racks.

For final drying cones should never be spread in layers more than 2 cones deep, even in air-temperature extraction on wire shelves or trays. In kilns, or in air extraction on tight floors, they should never be spread in layers more than one cone deep. Any apparent saving of space or of investment in equipment made by using deeper layers is false economy. Deeper layers delay drying, prolong the extracting period, and necessitate rehandling that more than offsets the saving in equipment costs. They often reduce the yield and quality of seed, and may prevent altogether the functioning of certain types of kilns.

The smaller the cones, the greater the area covered by a given volume spread in a layer 1 cone deep. The square feet required per bushel when so spread are, roughly: longleaf, 8; slash, 10; loblolly, 15; and shortleaf, 20. Exceptionally large cones may save 20 percent of the area ordinarily needed for the species--not more. Cones smaller than average require extra area per bushel (p. 501).

Cone trays, racks, or shelves should clear each other by at least the maximum length of the cone of the species to be extracted (p. 501) or twice the diameter of the cone when open, whichever is greater. Minimum practical clearances of trays or racks are from 3 to 4 inches for shortleaf to 8 to 10 inches for longleaf. If equipment is to be used for two or more species, clearances must fit the largest cones or be made adjustable (Rietz, 1941, pages 4 and 6)(____, pages 4 and 6). The clearance of wide, fixed shelves to be loaded and emptied by hand or with rakes or brushes, and of any shelves to be used for precuring, should be much greater, usually 16 to 18 inches, to allow both working space and free air movement.

Wire used for cone shelves or trays must be either fine enough to stop the smallest seed with the wing off (1/16-inch mesh screen wire suffices for the southern pines) or coarse enough to pass the largest seed with the wing still attached (p. 501). The larger is generally preferred; 1/2- or 5/8-inch square mesh meets most requirements, although 1/3-inch mesh may be necessary to prevent the passage of small unopened shortleaf cones. Intermediate meshes that will neither pass individual seeds nor let them be brushed off easily are an unmitigated nuisance.

Air-Temperature versus Kiln Extraction

The certainty that the seed will not be injured by artificial heat is one of the greatest advantages of air drying over kiln drying. Others are: relatively simple and inexpensive equipment; simpler technique; greater economy when the extractory is operating below full capacity; and less danger of fire.

Kiln extraction is, however, quicker than air extraction, especially in humid or rainy seasons. It reduces exposure of the seed to birds, rodents, insects, and physiological deterioration. Kiln drying requires less shed or tray space for large quantities of seed, because many cones go to the kiln from precuring racks, in which they have been spread 6 to 8 cones deep instead of in single layers. At the end of the collecting season they may go to the kiln directly from sacks. Kiln extraction often gives slightly better yields per bushel than air drying and in most of the southern pine region reduces seed to more nearly the right moisture content for storage.

Single layers of cones on floors and double layers on wire-bottomed shelves or trays dry out and open about equally well. Where floors tight enough to hold seed and smooth enough to permit sweeping it up are available during the extracting season, their use saves building special equipment. Otherwise tiers of shelves or of movable trays give the freest circulation of air among the most cones with the smallest investment in walls and roof. The tiers may be installed in existing buildings or housed in special sheds. Cone sheds (fig. 13) are usually about 18 by 80 feet, with five 6- by 80-foot shelves, 16 inches one above another, on each side of a 6-foot aisle. At full loading, including that of movable trays bridging the aisle at all shelf levels, and of the floor, such a shed holds about 1,060 bushels of longleaf cones, 850 of slash, 570 of loblolly, or 420 of shortleaf, spread one layer deep. For temporary storage or precuring, total capacities are three or four times these amounts. Blue prints and a bill of materials for a cone shed may be obtained from the Regional Forester, U. S. Forest Service, Atlanta, Georgia.

Figure 13.--Type of cone shed used by Region 8 of the U. S. Forest Service and by several southern States.

Kiln Extraction

To be effective, a cone kiln must supply enough hot air to dry the cones quickly--usually in less than a day; circulate the hot air freely and rapidly among all the cones in the kiln; keep temperature and humidity below levels injurious to the seed; and permit adjustment of temperature and humidity schedules to meet the requirements of different batches of cones.

The volume of hot air needed and the heater capacity required to supply it can be calculated closely from maximum safe temperature, cubic feet of kiln space, maximum pounds of water to be evaporated per charge of cones, rate of air discharge, and related data. Most of these values vary considerably from one kiln to another. As a rough general rule, however, a heater which will bring the air in the loaded kiln to maximum safe temperature in about 1 hour, and keep it there without difficulty, is big enough.

Rapid circulation of the air in contact with every cone serves two important purposes. One is to get all the cones dry and open as quickly as possible and at about the same time. The other is to keep the temperature of the seeds safely below that of the air in the kiln while the seeds are still moist, as they are in unopened cones freshly placed in the kiln. Seeds are most easily injured by high temperatures when they are that moist. As long as air movement is rapid, however, moist cones and the seeds they contain cannot become as hot as the kiln air, because they are cooled by evaporation from the cone surfaces. If, on the other hand, the air moves sluggishly, evaporation slows or ceases and the moist cones and seeds become as hot as the kiln air. Under such conditions, ordinarily safe kiln air temperatures may injure the seeds, and slightly higher temperatures may kill them outright.

Air movement in kilns can be tested with fumes of titanium tetrachloride (used for sky-writing with airplanes), or by means of talcum powder. Because of the fire hazard, tobacco smoke, joss-sticks, and the like are not recommended. The fumes or powder should move briskly in all parts of the kiln; any sluggish movement or dead air calls for adjustment of loading, vents, baffles, fans, or temperatures.

The U. S. Forest Service has used two types of forced-draft kilns, with optimum capacities of about 35 bushels of shortleaf cones and 135 bushels of longleaf cones, respectively, per charge. These kilns, which have proved much more satisfactory than convection-type kilns for drying large quantities of southern pine cones, extract seed without injury in 4 to 16 hours (usually in 8 to 10 hours), at costs ranging from 12 to 65 cents per pound of seed (usually about 25 cents), including depreciation of the kilns. Rietz has described in detail the design, operation, and performance of both these types of forced-draft kilns (Rietz, 1941)(___).

The one great disadvantage of such forced-draft kilns is their high initial cost, which only a fairly heavy and regular annual extracting load may justify. For small or irregular annual extractions by artificial heat, less expensive convection-type kilns may be preferable.

Air-movement in convection kilns depends almost entirely on the tendency of warm air to rise vertically and of cool air to sink; sidewise movement of air usually is negligible. The greater the contrast in temperature between the cold air outside a convection kiln and the artificially heated air inside, the brisker the air movement. For this reason, such kilns work better in November, when loblolly and longleaf cones become ready for kiln-drying, than in September, when slash cones need drying. The air also moves more briskly the higher the vertical channel or flue through which it rises or sinks. But at best the air in convection kilns moves with little force, and is inevitably slowed or stopped if layers of cones are too thick or too many.

Air heated to safe maximum temperatures will rise among and successfully dry out cones on 6 or possibly 8 wire screens inside a square, tight-walled flue not more than 5 by 5 or 6 by 6 feet in cross-section. The wire screens, which are easiest to load and unload if each consists of two removable trays, should be at least 12 to 18 inches apart, one above another. The higher (up to at least 8 or 10 feet) that the walls of the flue extend above the topmost tray, the more completely open the top of the flue, and the more freely the hot air can escape outdoors from the top of the flue, the faster the hot air inside the flue will rise past the cones and dry them out. One or a battery of such flues can be constructed in any suitable high-roofed building or shed. Each flue should have its own abundant supply of hot air, preferably from a steam pipe or coil. A baffle may be needed beneath the lowest screen in each flue, to make the hot air rise uniformly through all parts of the cross-section of the flue.

Where low ceilings, difficulty in supplying hot air separately to each flue, or need for greater capacity makes impossible the type of kiln just described, downward air currents around the walls of a room 15 by 15 to 20 by 20 feet may be used to dry cones. The requirements for effective drying in this way are: (1) a steam radiator or other source of heat in the middle of the room; (2) a flat, tight, fairly low ceiling; (3) tiers of wire-bottomed cone trays around all sides of the room with 8 to at most 12 trays per tier; and (4) generous vents all around the bottom of the room walls to drain off all the air descending through the cone trays. When the kiln is in operation, hot, dry air rises from the heater, hits the ceiling, and spreads outward toward the walls. As it reaches the cones in the topmost trays, it absorbs water from them and starts to cool. As it cools, the air settles through the trays, drying the cones and becoming still cooler as it goes, and finally escapes through the vents in the walls below the lowest trays. Canvas screens, parallel to the ceiling and extending from the inner edges of the topmost trays almost to the middle of the room above the heater, and canvas or wooden baffles extending from the bottom trays to the floor on the sides next to the heater, may be necessary to keep the air circulating through the trays of cones.

In a kiln using either upward or downward convection currents, the cold air intake leading to the heater, or the heater itself, must be below the floor. There must be no openings or channels through which the hot air can escape more easily than by passing through the trays of cones. And to permit easy passage of the air through the trays, it is imperative that the cones be spread in uncrowded single layers.

Although a few cone kilns in the South have utilized convection currents well enough to dry cones thoroughly and uniformly in 12 to 48 hours, other defects in design have made them excessively expensive to fill and empty. Numerous other convection kilns have failed because fundamental defects in design have made drying slow or uneven, or have injured the seed through overheating. There is need (Baldwin and Shirley, 1936)(____) for proved designs for efficient, reliable, home-made convection kilns capable of drying 20 to 50 bushels of southern pine cones in 8 to 12 hours. Such kilns should greatly facilitate procurement of good local seed, especially in poor crop years when it is important to get maximum yields per bushel by kiln-drying all cones.

It increases the efficiency of any kiln to construct it on a side hill, or with a ramp, so that cones can be unloaded from trucks onto the floor above the heater without lifting, be dried there, and be fed by gravity into the tumbler.

Since hot, dry, resinous, open cones are almost explosively inflammable, steam coils or radiators are far safer for any kiln than are stoves or hot-air furnaces. Oil-burning furnaces, automatically controlled, maintain the steadiest heat; coal furnaces are next best. Wood-burning heaters require considerable labor and close attention for satisfactory performance.

Efficient operation of any type of kiln demands at least a partial and preferably a complete extra set of trays, to be filled and ready for immediate insertion when a charge is removed.

Designing a kiln to insure adequate amounts and circulation of hot air is only half the story. To get the seed out of the cones without injury, it is necessary also to keep kiln temperatures and humidities safely below the highest levels the seed will stand. To get the seed out economically, temperatures and humidities must be combined in schedules that will dry and open the cones in brief, convenient periods without using excessive fuel. Neither safe levels nor economical schedules can be maintained without knowing and controlling kiln temperatures and humidities throughout each run.

To avoid overheating any seed, kiln temperatures are measured at a point as close as possible to the place where the incoming hot air first hits the cones. In a forced-draft kiln this usually is high on the wall opposite the air inlet. In a kiln utilizing upward convection currents it is under the lowest screen. In one utilizing downward convection currents it is above one of the topmost trays. No kiln should be without a direct-reading and preferably also a maximum thermometer at the point described, the former to guide the operation of the kiln and the latter to show that the maximum permissible temperature has not been exceeded at any time during the run. A recording hygrothermograph at the hottest point is essential to safe, efficient operation of a forced-draft kiln.

In any type of kiln, relative humidity usually is measured at the same point as temperature, to show whether the ingoing air is at the right combination of temperature and humidity (p. 94) ultimately to open the cones. It is useful also to measure relative humidity where the coolest, wettest air leaves the kiln, to make sure the air is removing moisture rapidly from the cones. If it is not, the temperature of entering air, the air circulation, or the loading or arrangement of the trays should be adjusted so that it does.

As a general rule, longleaf seed should be extracted at a maximum entering air temperature of 115° F. and loblolly, slash, and shortleaf at a maximum of 120° F.. Occasionally, longleaf has been extracted at 120° to 130° F., loblolly and slash at 130° F., and shortleaf at 140° F., without excessive injury, but these temperatures are not recommended. They should not be necessary to open mature, properly cured cones in well designed, well operated kilns. In one kiln, each 5° increase in kiln temperature between 115° and 135° F. caused a consistent decrease of 5.6 plantable seedlings per 100 longleaf seeds sown (Rietz, 1941)(___). Safe temperature limits for any species vary considerably with kiln design, loading and operation, duration of kiln run, and moisture content of the cones at the beginning of the run. Exact limits under the conditions most commonly encountered in a particular kiln can best be determined by opening several kiln-loads of cones at different temperatures and testing the germination of the seed from each load.

Although the exact humidity limits within which injury occurs have not been determined, it is known that prolonged high relative humidity in the kiln injures the seed. Simultaneous high temperature increases such injury. By contrast, the lowest humidities attainable under southern climatic conditions in kilns operated at maximum safe temperatures apparently do not injure southern pine seed within the periods needed to dry the cones. For these reasons, the safest rule is to run the kiln at all times at the lowest humidity attainable without wasting fuel. For an hour or more at the start of a run, the humidity cannot be brought as low as it can later. Moderately high humidity is least dangerous at the start of the run, however, because the rapid evaporation which keeps the humidity up also cools the cones and keeps the temperature of the seed many degrees below that of the kiln air. Keeping humidity as low as possible at all stages of drying not only safeguards the seed but expedites opening and removal of the cones. Within the limits set by weather conditions, kiln design, and maximum permissible kiln temperature, humidity is decreased mainly by increasing the rate at which the moist hot air is allowed to escape from the kiln through manually operated vents.

Since seed injury at any temperature is likely to increase with duration of exposure (Rietz, longleaf 1939; Rietz, White, 1939; Rietz, 1941)(__, __, __), seed should be removed from the kiln as soon as possible after the cones have opened completely.

Tumbling

Although fully dried cones shed most of their seed on drying floors or shelves or where they are emptied out of movable trays, they almost invariably have to be tumbled in a box or drum to get it all out.

For large quantities of cones, a progressive tumbler driven at 27 to 30 r.p.m. on a horizontal shaft by a $1\frac{1}{2}$ or 2 horsepower motor is highly efficient. It should be 10 feet long, 3 by 3 feet square at the small end, and 4 by 4 feet square at the large end (fig. 14). The sides should be covered with 5/8-inch square mesh manganese steel wire (1/3-inch for a tumbler used for shortleaf only), as ordinary hardware cloth lasts only a few hours in a tumbler of this capacity. Cones fed into the tumbler through a chute at the small end drop their seeds through the mesh into a catch tray as the tumbler revolves, and move to and discharge through the large end by gravity. For tumbling small lots of cones, a similar progressive tumbler 6 feet long, $3\frac{1}{2}$ by $3\frac{1}{2}$ feet at the small end, 4 by 4 feet at the large end, covered with $\frac{1}{2}$ -inch mesh hardware cloth, and turned by hand, is far more efficient than batch-type tumblers which require hand loading and unloading of each charge.

Figure 14.--Power-driven progressive cone tumbler. For specifications, write Regional Forester, U. S. Forest Service, Atlanta, Georgia.

For maximum seed yields, cones must be tumbled either on dry days or immediately after removal from the kiln. The relative humidity in the South is usually high enough to cause cone scales to close slightly and retain an appreciable portion of the seed.

Cones should be examined carefully after tumbling, and occasional samples redried at maximum permissible temperatures and retumbled, to make sure that extraction is complete. On a large job this precaution may save hundreds of dollars worth of seed (Eliason and Heit, red pine, 1940)(___).

Disposal of Cones

Open cones are so bulky that they must be disposed of currently. They make an undesirably hot, irregular fire for kiln furnaces, and are among the poorest of organic remains for nursery composts. At most extractories, therefore, they are incinerated. Incineration involves serious fire hazards unless at a considerable distance from buildings and in a burner with spark arrester. The belt conveying cones to the burner must be installed in a way to prevent its carrying fire back to the extractory.

The use of cone ashes for fertilizer or as an amendment to compost has not been adequately tested.

Cones not badly broken during tumbling may often be sold to novelty manufacturing companies.

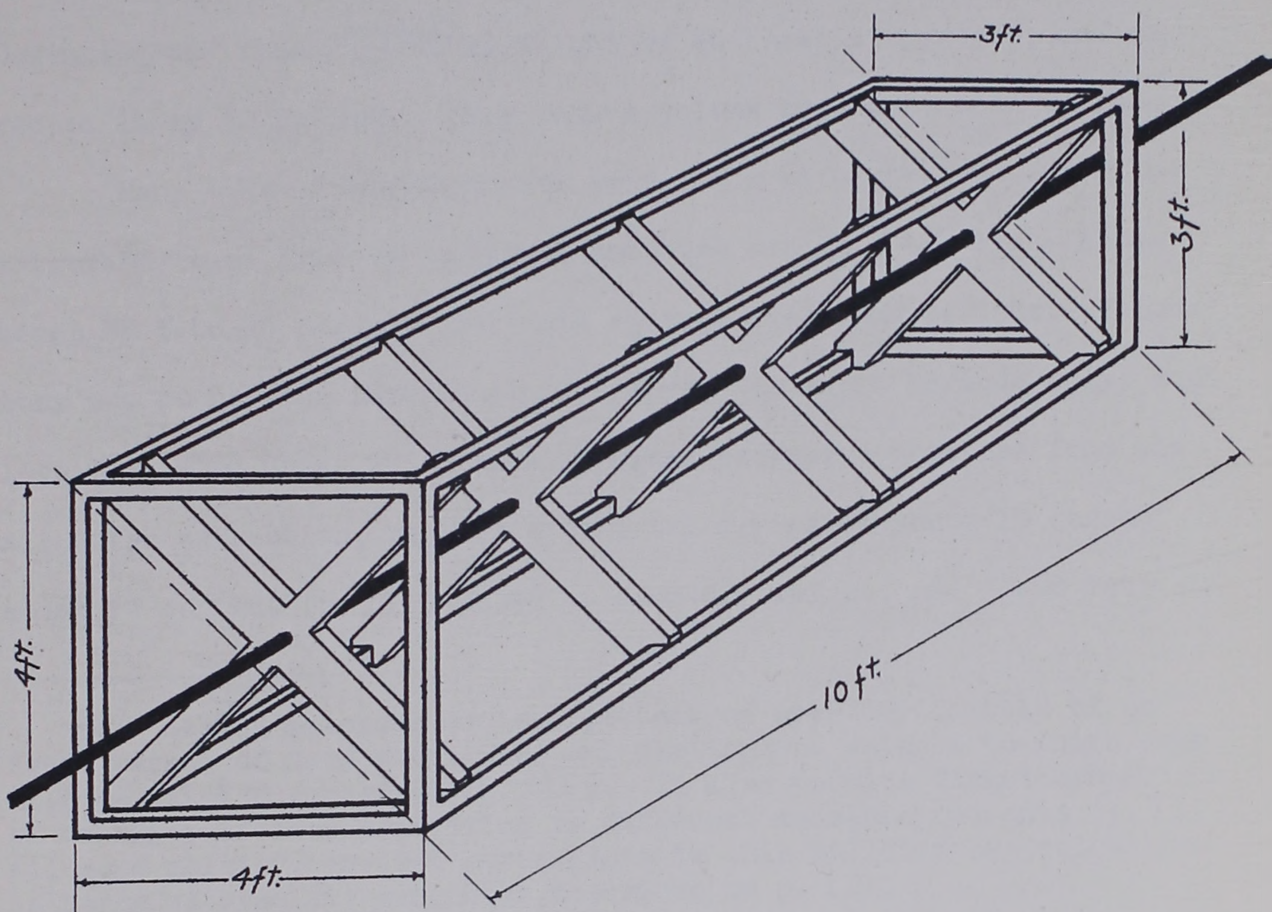


Figure 14.--Power-driven progressive cone tumbler. For specifications, write Regional Forester, U. S. Forest Service, Atlanta, Georgia.

DEWINGING, CLEANING, AND DRYING

Practically all pine seed is dewinged and cleaned to reduce shipping weight, storage weight and space, and outlay for containers, and to make the seed easier to mix, sample, test, package, sell, and sow. Dewinging and cleaning ^{usually} reduce weight by at least 15 percent, and may reduce it by 50 percent. They reduce volume even more than weight.

Many lots of southern pine seed, both air-extracted and kiln-extracted, come from the cones at moisture contents too high--sometimes by 5 to 25 percent--for safe storage over long periods. Unless they are to be sown immediately or stored for short periods only, such lots, and also those which have absorbed excessive moisture from the air after extraction, require artificial drying to about 10 percent moisture content (p. 131) based on oven-dry weight. ^{22/} Seed lots at

^{22/} Basing moisture content percent on oven-dry instead of on "wet" weight of seed simplifies calculations of weights to which seed must be dried for storage (p. 541). It also permits direct comparison of behavior of seed lots dried to different moisture contents (p. 133). All seed moisture content percentages in this bulletin are calculated in terms of oven-dry weight as described on p. 179.

the highest moisture contents cannot even be dewinged by the usual methods without first being dried.

Dewinging, cleaning, and drying usually are carried out in that order, immediately after the seed has been removed from the cones, and are guided by tests (pp. 167 to 193) of samples drawn during each process. Occasionally, however, very moist seed is dried before dewinging, or final dewinging and cleaning are postponed until after storage (p. 151) or stratification (p. 157).

There is less technical information about seed dewinging and drying than about any other phase of processing southern pine seed. It is known, however, that 30 percent or more of the seeds in some large, commercially dewinged lots have been injured mechanically during dewinging, and that many tons of seed have had their germination percent reduced by one-fourth to three-fourths or more by insufficient or faulty drying. Since such injuries seriously increase the cost of nursery stock by decreasing tree percent (fig. 10), tracing and eliminating them gives the collector or nurseryman one of his best opportunities to reduce costs.

Dewinging

The seed wings of all the southern pines except longleaf can be rubbed or broken cleanly from the dry seeds. No way of completely dewinging longleaf seed in bulk has been discovered; commercial "dewinging" merely reduces the wings to stubs. This reduction, however, saves much space, enables the seed to pass through mechanical seeders, and keeps it from blowing about during sowing. The drier the seeds of longleaf or other species, the easier the wings are to reduce or remove by ordinary methods.

Hand rubbing, though slow, is frequently the most economical method of dewinging small lots of seed. Some extractory operators prefer it even for large lots. Of all methods, it is least likely to injure the seed. For reasons of economy, however, most extractory operators prefer to use mechanical dewingers. The continuous-feed dewinger used by Region 8 of the U. S. Forest Service (p. 538) is driven at about 90 r.p.m. by a 1-h.p. motor, and has a capacity of 30 to perhaps 70 pounds of seed per hour, depending on species and cleanness.

To operate mechanical dewingers at full capacity without injuring the seed requires great care. The brushes must usually be of fiber instead of wire, and neither too soft to be effective nor so stiff as to crack the seed coats, especially of longleaf. They must be readjusted frequently to offset wear, and replaced before the bristles become so short as to lose their springiness. Care is also necessary in adjusting revolutions per minute and rate of feed. In some cases, the seed must be dried artificially before mechanical dewinging. Optimum adjustment and procedure must be determined and maintained for each dewinger and species by trial runs and by frequent close examinations of the seed (preferably with a hand lens), and also (Eliason and Heit, red pine, 1940)(____) by periodic germination tests of samples of dewinged seed (pp. 168 and 181), made while cleaning is still in progress, to reveal serious internal injuries to the seeds from too rapid revolution of the dewinger.

When the wing of a seed of any southern pine except longleaf is thoroughly moistened, the two curved prongs which attach the wing to the seed straighten out within a few seconds and the seed falls away at a touch. Advantage is sometimes taken of this fact in dewinging species other than longleaf. Either (1) the hands are dipped repeatedly in water during dewinging by hand rubbing; (2) the seed is spread on screens in layers about an inch deep, hosed until thoroughly moist, and stirred repeatedly until dry; or (3) before dewinging, the seed is chilled in contact with moist peat (to accelerate germination; see p. 157) and the loosened wings are removed with the peat.

Except with longleaf, these wetting methods frequently are cheaper than mechanical dewinging of dry seed. Their disadvantage is that they usually increase seed moisture content enough to cause deterioration or spoilage. The third method also necessitates a special calculation of sowing rates (p. 217). If seed dewinged by wetting cannot be sown or thoroughly redried the same day it is wet, it should be stored overnight at 35° to 41° F., and sown or redried the next day.

From the scanty evidence available (Smith and Webster, 1948) (___), hammermills, because of their tendency to scarify the seed-coats, cannot be recommended for dewinging southern pine seed.

Cleaning

The percentages of purity and soundness in table 9 are suggested standards for cleaning seed. They meet the needs of economical shipment and storage, reputable marketing, reliable sampling for testing, and good control of sowing rate. They have been attained with stock model or locally modified commercial cleaning mills, without excessive cost in labor or in loss of sound seed, though usually they have required two runs through the mill, and sometimes three.

As a preliminary to final cleaning, seed that has been hand-rubbed (or moistened, stirred, and dried) can be separated from the wings by placing it on a light, wire-bottomed tray, holding the tray shoulder high, and then lowering the tray quickly and swinging it to one side. The wings remain suspended in the air for a moment and then flutter clear of the tray. Such elimination of the wings increases the speed and exactness of later steps in the process of separating sound seed from empty seed and impurities.

Table 9.--Suggested minimum desirable and maximum feasible standards for cleaning southern pine seed in oscillating-screen, vertical-air-blast mills

Condition and species	: Purity		: Percentage	
	: percent <u>1/</u>		: of full seed <u>2/</u>	
	: Minimum	: Maximum	: Minimum	: Maximum
Wings intact, longleaf	90	95	85	90
Wings reduced to stubs, longleaf	90	95	90	95
Completely dewinged:				
Slash	95	99	95	98
Loblolly	95	99	85	90
Shortleaf	95	98	95	98

1/ Weight of externally normal looking, non-wormy, unbroken seed divided by total weight of all seed plus impurities, and multiplied by 100.

2/ Total number of seeds with kernels (determined by cutting test), divided by total number of externally normal-looking, non-wormy, unbroken seeds, and multiplied by 100.

The most efficient and uniform final cleaning requires a seed mill with two or more oscillating screens to separate seeds from larger and smaller impurities, and an adjustable upward air blast to separate light impurities and empty seeds from full seeds. The mill must have interchangeable screens for seed of various sizes; screen slope and the distance and speed of screen movement may also be adjustable (Turner and Johnson, 1948)(____). Even such mills, however, clean longleaf seed with the wings on less well than that with wings reduced, and dewinged loblolly less well than dewinged slash or shortleaf seed, because the contrast between the weights of full and empty seeds is less. (Dean, 1933)(____) (table 9). Moreover, they clean pine seed less rapidly than most agricultural seed, and at rates varying greatly with the state of the seed. The capacities per hour of power models commonly used range from perhaps 30 to 150 pounds of longleaf seed to a maximum of 450 pounds of the other pine species.

The table on p.501 is useful in selecting sets of screens for seed mills, but the most effective screen sizes, operating speeds, and rates of feed must be worked out locally by frequent sample weighings and cutting tests (pages 174 and 177). Too fast a feed must be avoided particularly. Fanning out more than 1 to 5 percent of all sound seeds usually necessitates refanning the accompanying trash to recover them.

Fanning seed is dusty work. Respirators frequently are necessary to workers' comfort and health. The fire and explosion hazard makes explosion-proof preferable to ordinary motors, and there must be no smoking. Where much seed is to be cleaned indoors, some dust-disposal system may be necessary.

Although good seed mills may be used to grade seed according to size as well as for cleaning, and such grading may make the resulting nursery stock more uniform in size, there seems little justification for separating seeds by size classes (Champion by Hasel, 1933; Eliason and Heit, Scotch, 1940; Erickson, 1946; Minckler, 1939; Minckler, 1942; Mitchell by Shirley, 1939; Perry and Coover, 1933; Reineke, 1942; Righter, 1945; Spurr, 1944)(____, ____, ____, ____, ____, ____, ____, ____, ____, ____). The principal effect would be to separate the seed of young from that of old trees (p. 78).

Southern pine seed--even longleaf with the wings on--can be separated fairly well from wing fragments and other light impurities by pouring it slowly from one container to another in a strong wind, or by dribbling it down a sloping screen over an uptilted electric fan. Since neither method gets out cone scales or many empty seeds, both are unsatisfactory for cleaning seed from wormy or badly broken cones, or that contains a large percentage of empties.

Most filled, completely dewinged seeds of loblolly, slash, and shortleaf pines sink in water; most impurities and empty seeds float. With these species, seed averaging 97 to 100 percent full can therefore be obtained by flotation (MacKinney and McQuilken, 1938)(____, and unpublished data). But cleaning by flotation increases the moisture content of the seed--a serious drawback except with seed chilled in a moist medium before dewinging (p. 157). It results also in losing some full seeds which fail to sink--usually at least 10 percent, and more if the seed is very dry or if many wing stubs still adhere. Flotation is useless for cleaning longleaf seed, which floats even when full and cleanly dewinged.

Drying

The best method for drying undesirably moist seed (p. 130) depends primarily on extraction method, drying and storage facilities, current weather, and the extent to which moisture content must be reduced. In some instances, facilities for testing moisture content may affect choice of method.

When the seed coming from a cone kiln is found to be too moist, later batches often can be dried satisfactorily in the same kiln by precuring the cones more thoroughly, by loading the kiln less heavily, or by changing the kiln schedule. In modifying the schedule, the kiln temperature may be increased, the relative humidity reduced, or the run lengthened. The first and last of these three changes must be made cautiously to avoid injuring the seed. Although all three will increase fuel consumption, the resulting reduction in seed moisture content should more than offset the extra fuel cost. A forced-draft kiln holding 5 trucks of loaded cone trays has turned out longleaf seed at moisture contents of 20 to 35 percent when all 5 truckloads have been inserted and dried simultaneously. When, however, the trucks have been moved through the same kiln progressively, removing a truck of dry cones from the tumbler end and inserting a truck of moist ones at the cone shed about every 2 hours, the seed has come out at about 8 to 10 percent moisture content.

Seed already extracted may be spread in shallow layers on wire-bottomed trays and dried by artificial heat in either a cone kiln or a special drier (Eliason and Heit, red pine, 1941)(____). Free movement of air over and among the seeds is essential. The hotter the air and the longer the exposure, the drier the seed will become, but excessive drying at any temperature may injure the seed (Barton, 1935)(____). Such injury increases with temperature, with duration of temperature, and with the moisture content of seed when drying starts, and is often intensified by subsequent storage of the seed. From available data, kiln temperatures and exposures for drying longleaf seed should not exceed 115° F. and 11 hours, respectively (Rietz, 1941)(____, and unpublished data). Little if any higher temperatures and longer exposures can be recommended for other southern pine seed. Even these drying schedules may cause dormancy, deterioration, or both.

In several ways direct sunlight is better than artificial heat for drying extracted seed. It reduces seed moisture content from relatively high levels to about the optimum for storage, apparently without ever reducing it too much. And although it sometimes increases seed dormancy, exposure to sunlight, in contrast to artificial heat, apparently never injures the seed. For these reasons, sunning seed in shallow layers in trays for several days is a safe and practical method for drying seed, particularly when lack of testing facilities prevents determination of moisture content. At one large nursery, seed has for many years been sunned with great success in 20-pound lots in loosely woven cotton sacks frequent shaken up and turned over. Overnight the seed should be returned to covered metal cans or dry, closed rooms to reduce reabsorption of moisture from damp air. Table 10 shows the effectiveness of 3 days of sunning upon matched samples of slash pine seed left at moderately high moisture content by fanning and at dangerously high moisture content by flotation. The germination tests revealed a little dormancy in sunned seed stored at 38° F., but showed that sunning greatly improved the keeping quality at room temperature.

The easiest and often the only feasible way to tell whether drying by artificial heat has progressed far enough or is in danger of going too far is by determining average seed moisture content and total weight at the start and then reweighing the seed during drying until it reaches a correct final weight calculated as described on p. 541.

Table 10.--Absolute germination percentages ^{1/} of slash pine seed stored in sealed containers after cleaning and drying by different methods

Methods of cleaning and drying ^{2/}	Storage temperature and period					
	38° F.			Room temperature		
	4 mo.	14 mo.	29 mo.	4 mo.	14 mo.	29 mo.
	<u>Percent</u>					
Fanning						
Sun	75	68	76	68	41	2
Shade	80	77	78	60	16	0
Flotation in water						
Sun	68	80	71	66	50	15
Shade	83	79	65	0	0	0

^{1/} Number of seeds germinated divided by number of seeds with kernels. The germination period was 30 days only, without pregermination treatment to break dormancy.

^{2/} Seeds dried in the sun were exposed in a shallow layer 7½ hours per day for 3 consecutive days before final sealing in containers. Those dried in the shade were exposed in shallow layers for only 6 hours before final sealing; these seeds were dry enough externally so that dust rose from them during stirring.

Some species of seeds endure slow drying at low temperatures better than fast drying at high temperatures (Crocker, 1948)(___). There is evidence that southern pine seed, especially longleaf, may belong to this class. Refrigerators in which the relative humidity is very low will greatly reduce the moisture content of southern pine seed in open-weave cloth sacks. Seed dried in this way from 13 or 15 percent moisture content to 8 to 10 percent appears to stand storage in such refrigerators better than seed placed in them after having been dried to the same level by moderate artificial heat. Where facilities are available, such refrigeration may be the best way to complete the drying of southern pine seed for storage.

In a few weeks or days, and sometimes even in a few hours, seed exposed to air of specific, constant temperature and relative humidity attains the equilibrium moisture content for the species and air conditions involved (Barton, 1941; Crocker, 1948; Toole, Toole, and Gorman, 1948)(___, ___, ___). That is, further exposure under the same conditions produces no further change in the moisture content of the seed.

Knowledge of the equilibrium moisture content percentages of southern pine seed at different combinations of air temperature and humidity has a direct and practical bearing upon both seed-drying and storage. Often, for example, it is the means of attaining the desired moisture content when refrigerators are used for final drying, or of maintaining the desired content when seed is stored in unsealed containers (p. 132) at any temperature. In drying seed during kiln extraction or by artificial heat after extraction, it helps to define various conditions under which the seed will dry sufficiently, including those which may result in overdrying if maintained too long.

The curves of figure 15 show the equilibrium moisture content percentages attained by longleaf pine seed at various combinations of temperature and humidity. The temperature and humidity combinations needed to bring longleaf seed to moisture contents intermediate between those shown can be approximated by interpolating points between the curves. Figure 15 also shows the important fact that longleaf pine seed, like many other seeds (Barton, 1941; Boswell, Toole, Toole, and Fisher, 1940; Toole, Toole, and Gorman, 1948)(___, ___, ___), requires a lower relative humidity to attain a certain degree of dryness at low temperatures than it does at high temperatures.

Figure 15. --Moisture content percentages of fresh longleaf pine seed (1938 crop, Mississippi, extracted at air temperature) in equilibrium with air at various temperatures and relative humidities.

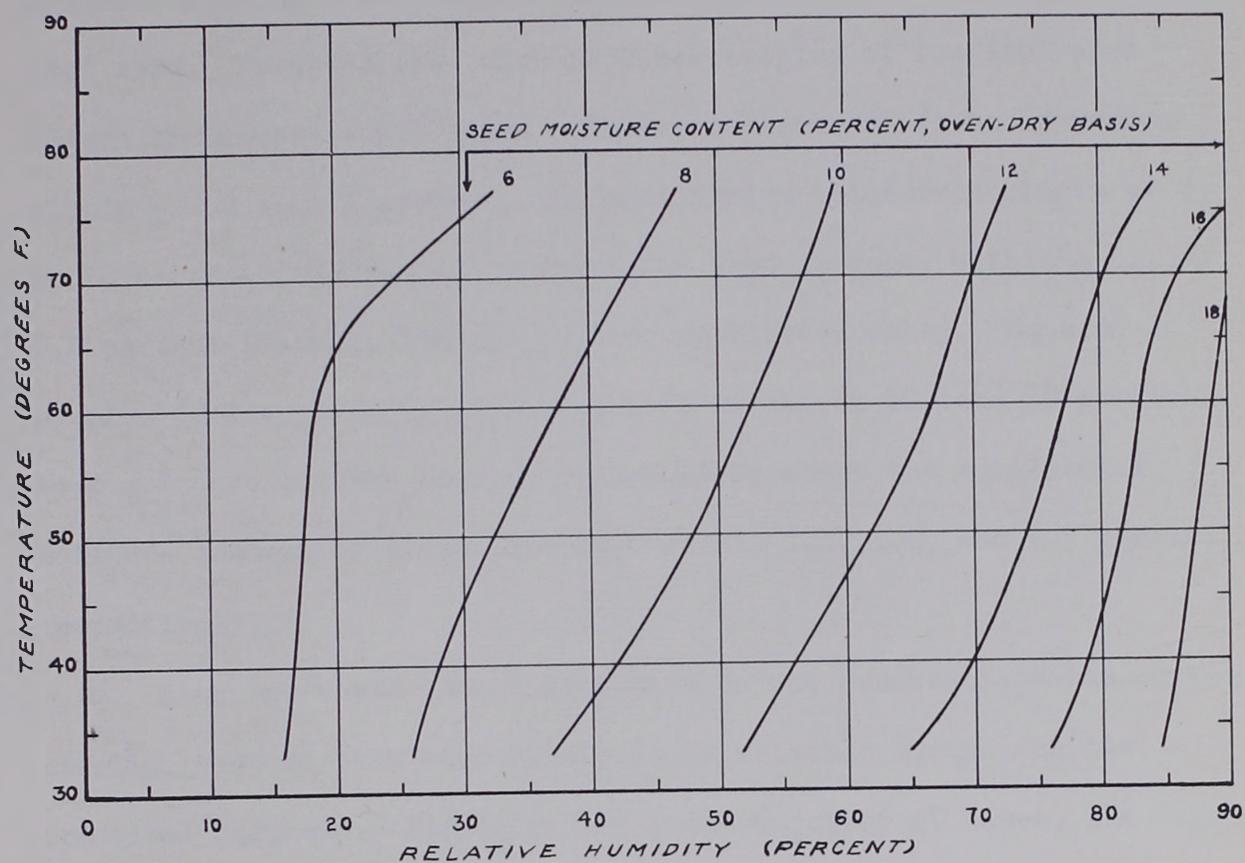


Figure 15.—Moisture content percentages of fresh longleaf pine seed (1938 crop, Mississippi, extracted at air temperature) in equilibrium with air at various temperatures and relative humidities.

Figure 15, although it is based on samples brought to equilibrium moisture content at 7 different humidities at each of 6 temperature levels, cannot be considered a precise guide to the drying of southern pine seed because all samples were from a single lot of longleaf seed. Nevertheless, with 12 other samples of longleaf seed, figure 15 forecast equilibrium moisture contents of 11 to 18 percent within ± 0.2 to 4.1 percent, and equilibrium moisture contents of 7 to 10 percent (the range important for seed storage) within ± 0.1 to 0.4 percent (Barton, 1941)(____, and unpublished data). Data on 3 samples (Coile, 1934)(____) showed that at the 6, 10, and 17 percent seed moisture content levels, figure 15 forecast the equilibrium moisture content of slash pine seed within 1.1, 1.0, and 5.5 percent, respectively.

Although these independent data do not substantiate the curves exactly, they do show that figure 15 is reliable enough for two practical purposes. First, in the great majority of cases, the figure should show whether the combination of average temperature and average humidity in a cone shed or extractory will dry seed enough for storage or for final drying in the refrigerator, or whether the seed will need additional drying by artificial heat or in the sun. Second, the portion of the figure to the left of the 10 percent seed moisture content curve should show closely the combinations of temperature and humidity needed for final drying of seed or to keep seed at a safe moisture content when stored in unsealed containers. A U. S. Forest Service cold-storage warehouse built and operated with figure 15 as a guide has kept thousands of pounds of longleaf and other southern pine seed at safe moisture contents and high viability for periods up to 4 years.

STORAGE

Sooner or later the success of practically every southern pine planting program depends upon seed which has been stored at least 1 to 3 years. The storage method used must keep a high percentage of the seed capable of vigorous germination, because low germination percentages greatly increase costs (fig. 10) (Gouffon, 1947)(____) and much seed that germinates weakly is no better than dead seed (Davis, 1941; Leach, 1947)(____, ____). Dry, cold storage ^{23/} is the most effec-

^{23/} The following references on dry, cold storage of other species give fundamental principles and practical details of the method: (Baldwin, 1942; Barton, 1941; Barton, 1947; Bates and Rudolf, 1938; Boswell, Toole, Toole, and Fisher, 1940; Clark, 1948; Durel, 1904; Mirov, 1946; Roe, 1948; Toole, Toole, and Gorman, 1948; U. S. Forest Service, 1948)(____, ____, ____, ____, ____, ____, ____, ____, ____, ____).

tive method yet developed for southern pine seed (Barton, 1935; Nelson, 1938; Nelson, 1940; Uebersezig, 1947)(____, ____, ____, ____).

Even in dry, cold storage, however, the generally effective combinations of temperature and seed moisture content have failed unaccountably with some seed lots. Some storage techniques that work well with small samples fail with large lots of seed, apparently because the sheer mass of a large lot impedes drying or chilling, or prevents the dissipation of heat released during normal respiration. Certain conditions typical of most or all southern pine extractories and nurseries complicate storage. These include comparatively high air temperatures and humidities; large seed lots that require considerable time for processing and much container and storage space; and the extreme sensitivity of longleaf seed to adverse conditions during storage.

The practical difficulties of storing southern pine seed can best be overcome if three main facts are kept in mind:

1. So long as a seed is alive, it respires. That is, it consumes the elaborated plant food it contains; it uses oxygen; it liberates carbon dioxide, water, and heat. The rate of respiration increases tremendously with rises in temperature and seed moisture content and with injury to the seed (Karon and Altshul, 1946; Miller, 1938)(__, __). Some respiration is essential to continued life of the seed, but too much rapidly depletes the stored food on which seedling growth depends (Gast by Huberman, 1937; Gast by Kittredge, 1937)(__, __). The immediate cause of the weakening or death of seed in storage appears to be degeneration of the nuclei of cells in the embryo (Crocker, 1948)(__), but such degeneration must almost inevitably follow excessive respiration. Keeping respiration very little above the minimum safe level is therefore basic to successful seed storage.

2. Seed is in storage from the time the cone matures until pregermination treatment or sowing--not just while in containers or buildings specifically set aside for storage purposes. For example, many lots of southern pine seed properly refrigerated most of the time between extraction and use have lost significant and economically important percentages of their germinability during brief exposure to adverse conditions before refrigeration or between refrigeration and sowing.

3. Storage can succeed only when all influences that materially affect respiration are kept at favorable levels. Keeping just one important influence (storage temperature, for example) at optimum without controlling the rest cannot be depended upon to preserve the seed, because an injurious extreme of any other (such as seed moisture content) may then cause storage failure. The initial soundness and vitality of the seed, together with temperature and moisture content, are among the principal influences to consider (Brett and Weston, 1941; Clark, 1948; Eliason and Heit, red pine, 1940; Mirov, 1946; Rietz, 1941; Stevens, 1935)(____, ____, ____, ____, ____, ____). The fact that refrigeration or dryness cannot replace depleted food reserves or repair injured embryo tissue seems too obvious to require comment, yet it frequently is ignored in practice.

In the light of these three main facts, seed storage is a technique for keeping respiration at the minimum safe level, food reserves at a maximum, and embryo tissues uninjured, usually for long periods. The details of the technique may and often must be varied to fit species, available facilities, and probable duration of storage. It should be noted that any technique has a better chance of succeeding if it keeps the seed as insensitive as possible to minor or brief changes in storage environment. 24/ For example,

24/ This is the reverse of the object of certain pregermination treatments commonly called stratification (p.157). This type of stratification, unlike the type used to preserve nut fruits over winter by keeping them at the high moisture content they require, should never be confused with storage (Mirov, 1936)(____) or be depended upon to preserve southern pine seed beyond definite, brief periods--45 days in commercial practice.

dry seed is unaffected by a brief period of increased temperature during the defrosting of a storage refrigerator, whereas such a change sometimes makes moist seed mold and wet seed sprout.

Temperature, Moisture, and Containers

As a general rule, decreasing the storage temperature improves the keeping quality of stored seed.

In particular, temperatures above 41° F. should be avoided, because both the respiration of seeds and the deterioration of stored seeds appear to increase in rapidity with each increase in temperature above this level. Barton, for example, has shown that the germinability of longleaf seed decreases much more rapidly at 50° than at 41° F. (Barton, 1941)(____).

Temperatures between 32° and 41° F. seem about equally acceptable for storage, but even within this range the lowest temperatures probably are best.

For many years it was assumed that temperatures below 32° F. would injure the seed of the "warm climate" southern pines, but there is no evidence that this is true except when seed moisture content is very high (Crocker, 1948)(____). Barton found that temperatures ranging from 5° to 23° F. kept seed of all 4 principal southern pines in excellent condition for at least 6 years (Barton, 1935)(____). Indeed, reanalysis of Barton's published data by statistical techniques not generally available when she began her study has shown that in many instances seed kept significantly better at these temperatures than at 41° F. This finding is of great practical importance not only because it opens the way to better maintenance of seed viability than may be possible at 32° to 41° F., but particularly because commercial cold storage facilities at approximately 5° F. are more generally available than those at 32° to 41° F.

Within a range of several percent below a level known as the critical moisture content percent, the exact moisture content ordinarily has little effect on the keeping quality of uninjured seed (Barton, 1941)(____). By contrast, each increase in seed moisture content above the critical moisture content percent accelerates respiration and deterioration, much as does each increase in temperature above 41° F.

The critical moisture content percent is not, however, the same for all storage conditions and all seed lots. It apparently lies at a higher level when storage temperatures are low than when they are intermediate or high; details of these relationships are presented later. It also differs greatly according to the kind of seed (Barton, 1941) (___).

For longleaf pine seed stored at 32° to 41° F., the critical moisture content appears to be almost exactly 10 percent. Some evidence indicates that the critical moisture content of other southern pine seeds is the same; other suggests that it may be as high as 12 or 13 percent, though certainly no higher than 15 percent. Until higher levels are confirmed for species other than longleaf, the 10 percent level should be assumed for all southern pines.

Ordinarily, southern pine seeds should be stored approximately at or just below the critical moisture content percent (p. 145). Like other pine seeds and fatty seeds in general, they may be dried to 6 or 5 percent without injury (Crocker, 1948)(___). Drying them even to 1 percent may not cause complete loss of viability (Barton, 1935)(___). Even the critical moisture content percent, however, frequently induces some dormancy, and successively lower levels increase the likelihood both of severe dormancy and of permanent injury.

There is abundant evidence that fluctuations in seed moisture content during storage reduce viability of many kinds of seed (Barton, 1941; Barton, 1943; Barton, 1947; Brett and Weston, 1941)(___, ___, ___, ___). In the light of data presented later, this seems to be true of southern pine seed.

The relative humidity inside air-tight, sealed containers, or inside the storage chamber if containers are not sealed, greatly affects the success of storage (Barton, 1941; Barton, 1943; Barton, 1947; Boswell, Toole, Toole, and Fischer, 1940; Clark, 1948; Coile, 1934; Toole, Toole, and Gorman, 1948)(____, ____, ____, ____, ____, ____, ____) by its effect on seed moisture content, which rapidly approaches, and fairly soon stabilizes in, equilibrium with the air. Southern pine seed comes into equilibrium much as shown in figure 15.

Containers influence the keeping quality of southern pine seed largely, if not entirely, through their effect on seed moisture content. This effect depends upon whether sealing (as in glass fruit jars with rubber rings), moderately tight covering (as in slip-top tin cans), or free admission of air (as in burlap or cheese cloth sacks) maintains the initial moisture content of the seed or lets it change slowly or rapidly. There is scant evidence that refinements such as exhausting the air from sealed containers do much good; the reanalysis of Barton's data already referred to, for example, showed only slight advantages from vacuum-sealing shortleaf pine seed, and none from vacuum-sealing longleaf, slash, and loblolly seed. For these reasons, containers should be chosen primarily for their effects on seed moisture content and secondarily for low initial cost and low cost of filling and emptying (p. 143). Thorough understanding of these facts clarifies many of the published recommendations concerning containers (Baldwin, 1942; Toumey and Korstian, 1942)(____, ____).

It must be emphasized that maintaining a favorable combination of temperature and seed moisture content (the latter often through choosing the right container) is far more important to successful storage than is choice of temperature, initial seed moisture content, or container alone. And no combination can work well unless the seed is sound and of high vitality at the start. The following sections 25/

25/ Most of the original research reported in them, and part of that reported in several other sections on seed, was by Mary L. Nelson, formerly at the Southern Forest Experiment Station.

on long-time and overwinter storage illustrate these facts in detail.

Storage for One or More Years

Prolonging the period of storage intensifies differences in the results obtained from different storage methods. The following studies were continued for 5 years to show the most reliable of several different techniques for storing southern pine seed for the 1 to 3 years frequently required in practice.

Fresh longleaf pine seed from the 1937 crop, extracted at a moisture content of 18 percent and cleaned without dewinging, was stored in all possible combinations of 5 initial seed moisture contents, 4 types of containers, and 2 environments (commercial warehouse at 41° F., and normally heated office), a total of 40 different storage treatments (table 11). After storage for different periods, up to 5 years, samples were laboratory-tested in replicate, and germination percentages were transformed to arc $\sin\sqrt{\text{percentage}}$ values 26/ for

26/ This transformation and the reasons for it are discussed in (Bartlett, 1947; Snedecor, 1946, pages 445-450)(____, ____, pages 445-450).

analysis of variance. All averaging was performed on transformed values, and the averages were then converted back to the percentages in table 11.

Table 11.--Five-year storage of 1937 longleaf pine seed at two temperature levels and varying seed moisture contents

Approximate initial :		Germination percent <u>2/</u> at 32 to 38 days						
moisture content of seed; storage con- tainer <u>1/</u>	:	Before storage		After air-tempera- ture storage for:		After storage at 41° F. for:		
						1 year:	2 yrs:	4 yrs:
<u>6 percent</u>								
Sealed glass jar	77	62	0	88	82	71	47	
Sealed glass jar with charcoal	77	36	0	89	88	61	55	
Slip-top tin can	77	1	0	84	86	52	32	
Cheesecloth sack	77	0	0	85	92	60	21	
<u>9 percent</u>								
Sealed glass jar	76	1	0	89	92	78	40	
Sealed glass jar with charcoal	76	2	0	89	87	75	43	
Slip-top tin can	76	1	0	88	83	58	14	
Cheesecloth sack	76	0	0	82	84	48	28	
<u>12 percent</u>								
Sealed glass jar	83	0	0	85	87	32	18	
Sealed glass jar with charcoal	83	0	0	90	75	48	17	
Slip-top tin can	83	1	0	96	84	41	16	
Cheesecloth sack	83	1	0	82	76	30	15	
<u>15 percent</u>								
Sealed glass jar	83	0	0	69	78	14	13	
Sealed glass jar with charcoal	83	0	0	69	71	37	1	
Slip-top tin can	83	1	0	87	73	41	19	
Cheesecloth sack	83	0	0	82	76	42	16	
<u>18 percent</u>								
Sealed glass jar	87	0	0	50	0	0	0	
Sealed glass jar with charcoal	87	0	0	70	1	0	3	
Slip-top tin can	87	0	0	86	79	30	5	
Cheesecloth sack	87	1	0	77	76	46	21	

^{1/} Sealed glass jars maintained initial moisture contents essentially unchanged throughout storage; slip-top tin cans permitted gradual increases of low moisture contents and decreases of high ones; cheesecloth sacks permitted similar but more rapid changes.

^{2/} See footnote 26, p. 133 .

Table 11 shows that only two of the 20 air-temperature treatments kept substantial percentages of longleaf seed alive for 1 year; both involved maintenance of seed moisture content at 6 percent by sealed glass jars. No treatments kept seed alive 2 years at air temperature. At 41° F., seed kept well for 4 years and fairly well for 5 years when maintained at 6 or 9 percent moisture content. It kept well for 2 years when stored at higher initial moisture contents in containers that permitted drying in storage. Maintained high moisture contents consistently reduced the duration of successful storage; longleaf seed maintained at 18 percent moisture content by sealed jars deteriorated considerably within 1 year and was dead at the end of 2 years, despite refrigeration. Sealed containers, which kept the seed dry, were superior to unsealed when seed was stored at initial moisture contents of 6 and 9 percent. Unsealed containers, because they enabled the seed to dry out, were superior to sealed when initial moisture contents were 15 or 18 percent.

Table 12 gives details of a similar test (with only 2 types of containers) of slash pine seed of the 1939 crop, freshly extracted, de-winged, and cleaned, and with an original seed moisture content of 18 percent. As with longleaf pine seed and with the slash pine seed in table 10, cold storage proved far superior to storage at office air temperature. At air temperature, the slash seed placed in storage at 6 to 15 percent moisture content held up fairly well for one year in either sealed glass jars or slip-top tin cans. So did seed initially at 18 percent when stored in slip-top cans, presumably because the cans permitted some drying. In sealed jars, seed at 18 percent moisture content died within the first year. At air temperature, only the seed maintained at 6 percent moisture content by sealed jars remained usefully viable for 2 years, and no combination kept seeds alive beyond the third year. By contrast, all lots of slash seed stored at 41° F. remained usefully viable for 5 years.

Table 12, however, shows two distinct patterns of deterioration among slash pine samples stored at 41° F. First, the seed maintained at 18 percent moisture content by sealed glass jars deteriorated badly during the fourth and fifth years as compared to all other lots stored in glass at 41° F. Second, the lots originally at 6 and 9 percent moisture content, and stored in cans at 41° F., deteriorated distinctly more by the end of the fifth year than did the moister lots in cans. This deterioration of seed dried below the level of moisture equilibrium with the air of the storage chamber and allowed to increase in moisture content during storage has been observed in other studies and in commercial storage of southern pine seed. It seems to be an instance of the unfavorable effect, previously mentioned, of fluctuating moisture content during storage.

Table 12.--Five-year storage of 1939 slash pine seed at two temperature levels and varying seed moisture contents

Initial	:	Germination percent ^{2/}	at 31 to 35 days
moisture content:	Before:	After air-tempera-	After storage
and	: stor-	ture storage for:	: at 41° F. for:
container ^{1/}	: age :	1 yr.: 2 yrs.: 3 yrs. ^{2/}	: 1 yr.: 2 yrs.: 3 yrs.: 4 yrs.: 5 yrs.

6 percent

Sealed glass jar	57	62	50	1	76	71	75	72	74
Slip-top tin can	57	58	7	0	77	74	81	79	52

9 percent

Sealed glass jar	65	65	1	1	76	84	74	75	65
Slip-top tin can	65	61	2	0	77	80	86	77	59

12 percent

Sealed glass jar	63	41	1	0	77	86	65	64	74
Slip-top tin can	63	53	4	1	76	75	75	75	71

15 percent

Sealed glass jar	63	56	6	0	73	87	67	70	60
Slip-top tin can	63	64	3	0	76	86	77	71	66

18 percent

Sealed glass jar	62	0	0	0	71	84	72	57	45
Slip-top tin can	62	57	7	0	71	80	87	69	64

^{1/} Sealed glass jars were intended to maintain initial moisture contents throughout storage, but moisture-content determinations at the time of some tests showed that moisture contents of a few samples had changed appreciably. The slip-top tin cans permitted the moisture contents to change much more freely; in general, the high ones decreased and the low ones increased by several percent.

^{2/} See footnote 26, p. 133.

^{3/} No samples stored at air temperature were viable after the third year.

The results of several other longleaf and slash pine storage studies confirm and extend the results just described. A 2-year study of 1936 longleaf seed, for example, showed that at 38° F., seed at 18 and 22 percent moisture content deteriorated seriously within 1 year and died within 2 years, whereas seed at 6 to 13 percent moisture content kept reasonably well for 2 years at this temperature. At office air temperature in the same study, seed maintained 1 and 2 years at 6 percent moisture content germinated 49 and 20 percent, respectively, whereas seed maintained at 10 to 22 percent moisture content failed to keep even 1 year. In another study, longleaf seed germinated 61 percent and slash seed germinated 91 percent after 10 and 17 years respectively at 35° to 38° F. and approximately 10 percent seed moisture content.

These studies show that slash pine seed is less exacting than longleaf in its requirements for long storage, but suggest strongly that it should be refrigerated at a moisture content no higher than 12 percent, and no lower than 9 percent unless sealed containers are used. Less is known about the combined effects of storage temperature and seed moisture content upon the keeping qualities of loblolly and shortleaf seed. From earlier studies (Barton, 1935; Nelson, 1938; Nelson, 1940)(__, __, __) and results in commercial practice, however, it is clear that storage requirements for loblolly and shortleaf seed resemble those for slash seed more closely than those for longleaf. Shortleaf seed, like slash, has been stored successfully for 17 years at 35° to 38° F. and approximately 10 percent seed moisture content, whereas longleaf has not been stored successfully under these conditions for more than 10 years.

Overwinter Storage

The need for special storage treatments to preserve southern pine seed from collection in the fall until sowing the following spring became painfully evident in 1935 and 1936. In those years thousands of pounds of longleaf seed in unheated buildings deteriorated badly or spoiled completely within 2 months after extraction. Simultaneously, it was discovered that less readily discernible deterioration of seed overwinter was a principal cause of low nursery tree percent (Huberman, Jour. Forestry, 1940)(___). The following studies were undertaken to learn what weaknesses in current practices were causing losses of seed and whether techniques less exacting than those required for several years' storage could be depended upon to keep seed over winter.

Longleaf pine seed extracted in November 1936 at a moisture content slightly in excess of 22 percent was prepared for storage in December in all eight possible combinations of moisture contents, seed wings on and off, and containers, as indicated in table 13. Laboratory germination percentages of the seed when placed in containers were: dry, wings on, 69 percent; dry, wings off, 66 percent; wet, wings on, 78 percent; and wet, wings off, 76 percent.

Table 13.--Laboratory and nursery germination of 1936 longleaf pine seed stored 2-1/2 months by 32 different methods

Environment	Container	Seed moisture content		Average germination percent ^{1/}					
		Initial (percent)	Apparent during storage ^{2/}	Seed with wings on			Seed with wings off		
				Labora- tory	Stuart Nursery	Ashe Nursery	Labora- tory	Stuart Nursery	Ashe Nursery
Refrigerator, ^{3/} 38° F.	Glass	9	Constant (low)	71	70	66	60	70	60
	Cloth	22	Greatly reduced	73	73	72	72	61	64
	Cloth	9	Slightly reduced	70	65	76	65	56	61
	Glass	22	Constant (high)	80	80	79	73	55	41
Average for refrigerator				74	72	73	67	61	57
2-bushel burlap bags ^{4/}	Glass	9	Constant (low)	67	68	65	64	59	57
	Cloth	22	Greatly reduced	50	53	59	38	38	42
	Cloth	9	Fluctuating but low	43	59	50	40	44	36
	Glass	22	Constant (high)	57	0	5	0	0	2
Average for burlap bags				54	38	42	29	29	30
Storehouse shelf	Glass	9	Constant (low)	62	67	69	54	67	52
	Cloth	22	Greatly reduced	54	63	56	51	48	39
	Cloth	9	Fluctuating but low	53	60	61	36	38	37
	Glass	22	Constant (high)	1	1	1	0	0	1
Average for storehouse shelf				36	41	40	29	31	28
30-gallon galvanized iron cans ^{5/}	Glass	9	Constant (low)	68	73	70	68	61	60
	Cloth	22	Considerably reduced	16	43	30	1	25	24
	Cloth	9	Somewhat increased	29	28	22	6	5	11
	Glass	22	Constant (high)	41	0	1	21	0	3
Average for galvanized iron cans				38	30	26	18	16	21
Grand average for all				51	45	45	35	34	33

^{1/} See footnote 26, p. 133. Major failures of laboratory germination to predict nursery germination are indicated by bold-face type.

^{2/} Judged from determinations of moisture content of surplus seed from samples tested in laboratory, and from general observations of environments.

^{3/} Air inside very dry, because of condensation of moisture on cooling unit.

^{4/} Filled with seed at about 20 percent moisture content and with wings on. Seed better aerated than that in galvanized iron can; temperature probably lower and certainly more uniform than that on storehouse shelf.

^{5/} Filled with seed at about 20 percent moisture content and with wings reduced to stubs. Aeration poor; temperature, because of respiration of seed, probably higher than in any other environment.

Seed in each of the eight combinations was stored in each of four contrasting environments (table 13), making 32 different storage treatments in all. The 2-bushel bags and the 30-gallon cans were in a large, unheated nursery storeroom containing several tons of fresh longleaf seed in burlap bags; the shelf was near the ceiling of the same room. The refrigerator and open shelf duplicated environments used in earlier laboratory studies of seed storage. The bags and cans duplicated environments common in large-scale storage. The previous year there had been wholesale spoilage of longleaf seed stored at about 20 percent moisture content in 30-gallon ash cans.

In the refrigerator and on the shelf, the containers were spaced to allow free air circulation around each cheesecloth sack and glass jar. In the 2-bushel bags, each sack or jar was completely surrounded by moist seed with the wings on; in the ash cans, by moist dewinged seed. In the refrigerator, the wet seed in cheese-cloth sacks dried considerably through condensation of moisture on the cooling unit. In the burlap bags, on the shelf, and in the ash cans, most of the wet seed in cheese cloth sacks dried considerably, and the dry seed in cheesecloth sacks in the ash can became more moist; the direction and extent of these changes depended on the moisture equilibrium which developed between the samples and the surrounding air, or air and moist seed. In all 4 environments, the sealed glass jars kept the stored samples essentially at their initial moisture contents of 9 or 22 percent.

Each of the 32 different treatments was applied to 3 samples. In March, 1937, at the height of the sowing season and after only $2\frac{1}{2}$ months' storage, the samples were used for simultaneous, comparable germination tests in the laboratory and in the seed beds of two U. S. Forest Service nurseries. Germination in the laboratory and in each nursery ranged from about 80 percent down to zero, depending upon storage treatment (table 13). One-fourth of the 32 different treatments resulted in laboratory or nursery germination, or both, of less than 10 percent--a striking illustration of the importance of correct over-winter storage.

Table 13 shows that almost without exception the seed with wings on germinated better, and in many instances conspicuously better, than similarly stored and tested seed with wings reduced to stubs. The refrigerator was by far the most favorable environment and the galvanized iron can full of moist dewinged seed was distinctly the least favorable. Within environments, keeping quality varied greatly with container and initial seed moisture content. Germination of seed stored in the refrigerator ranged downward from 80 to 41 percent; that in each of the other 3 environments ranged downward from about 60 or 70 percent to zero.

Table 14 shows that the average germination percentages of the samples stored in cheesecloth containers were generally somewhat higher than those of the corresponding samples stored in sealed glass. The averages for all samples dried to 9 percent moisture content consistently excelled those placed in storage at 22 percent moisture content. The greatest differences in table 14, however, appear among the average germination percentages of seed kept at constant low, fluctuating intermediate, and constant high moisture contents throughout the 2-1/2 months of storage. These results show that containers were relatively unimportant by themselves but extremely important in connection with initial seed moisture content. Table 13 shows in more detail that where containers kept dry seed dry or allowed moist seed to dry, results were excellent or good, but where they allowed dry seed to become moist again, and especially where they kept moist seed moist (except at 38° F.), they injured or ruined the seed.

In neither nursery did the average germination for all treatments differ significantly from the laboratory average--an important point in connection with seed testing and nursery sowing rates (pp.191 and 215). In 6 of the 32 individual treatments, however, there were serious discrepancies in germination between laboratory and nursery, or between the two nurseries (bold-face figures, table 13). The concentration of these discrepancies among samples of seed at high moisture content, or dewinged, or both, and especially in the galvanized iron cans, shows that, in addition to wasting seed and increasing costs, incorrect overwinter storage may decrease the reliability of germination tests as guides to sowing rates.

Table 14.--Average laboratory and nursery germination of 1936 longleaf pine seed stored 2-1/2 months, for subheads of table 13

Table 13 subhead	Average germination percent ^{1/}					
	Seed with wings on			Seed with wings off		
	Labora-	Stuart	Ashe	Labora-	Stuart	Ashe
	tory	Nursery	Nursery	tory	Nursery	Nursery
Container						
Cloth	48	56	52	35	38	38
Glass	53	35	39	35	29	29
Initial moisture content						
9 percent	58	61	59	48	49	46
22 percent	43	30	32	23	20	22
Moisture content during storage						
Constant, 9 percent (in glass)	67	70	68	62	64	58
Fluctuating interme- diate (all seed in cheesecloth)	48	56	52	35	38	38
Constant, 22 percent (in glass)	39	8	13	13	4	7
Grand average for all	51	45	45	35	34	33

^{1/} See footnote 26, p. 133.

Longleaf pine seed of the 1937 crop, freshly extracted at a moisture content of 18 percent and cleaned without dewinging, was stored for 1 and for 3-1/2 months at each of 60 possible combinations of 5 seed moisture contents, 4 containers, and 3 environments (electric refrigerator at 38° F., unheated shed, and normally heated office) (figure 16). Laboratory germination tests, in replicate, confirmed and extended the results of the 1936 overwinter storage test.

Figure 16.--Varying effects of containers upon 1937 longleaf seed stored 3-1/2 months, depending upon initial moisture content of seed. (Averages of samples stored at 38° F., in unheated shed, and in heated office. The specially graduated percentage scale is necessary when averages are derived from arc sin $\sqrt{\text{percentage}}$ values; see footnote 26, p.133.)

At the end of 1 month, very significant differences in germination appeared among the averages for the three environments--refrigerator 80 percent, unheated shed 76 percent, and heated office 71 percent.

At the end of 3-1/2 months, not only temperatures, but also seed moisture contents and containers, both alone and in combination, had very significantly affected the germinability of the stored seed. Average germination percents for refrigerator, unheated shed, and heated office were 63, 35, and 29 percent, respectively. For seed with initial moisture contents of 6, 9, 12, 15, and 18, average germination percents were 53, 50, 46, 37, and 24 percent, respectively. For slip-top tin can, cheesecloth sack, sealed glass jar with charcoal, and sealed glass jar without charcoal, they were 47, 46, 39, and 36 percent, respectively; here the can and cloth did not differ significantly, nor did the two jars, but all other differences among containers were significant.

The interactions between initial moisture content and container-- that is, the differential responses of seed at various moisture contents to various containers--were very significant and of great practical interest. Figure 16, which averages (for each initial moisture content and each container) the germination percentages for all three environments, shows these interactions clearly. When longleaf seed entered storage at 6 or 9 percent moisture content, sealed containers, which kept it dry, were slightly better than unsealed. When seed went into storage at 15 or 18 percent, sealed containers, because they kept it wet, were far poorer than unsealed, even for so brief a storage period as $3\frac{1}{2}$ months.

When the three-way interactions of temperature, initial moisture content, and container were analyzed at the end of $3\frac{1}{2}$ months' storage, the results very strongly confirmed the findings of the 1936 study in favor of dry cold storage, with drying during cold storage as second choice, and dry storage at intermediate temperatures as third choice, even for the short period between extraction and spring sowing.

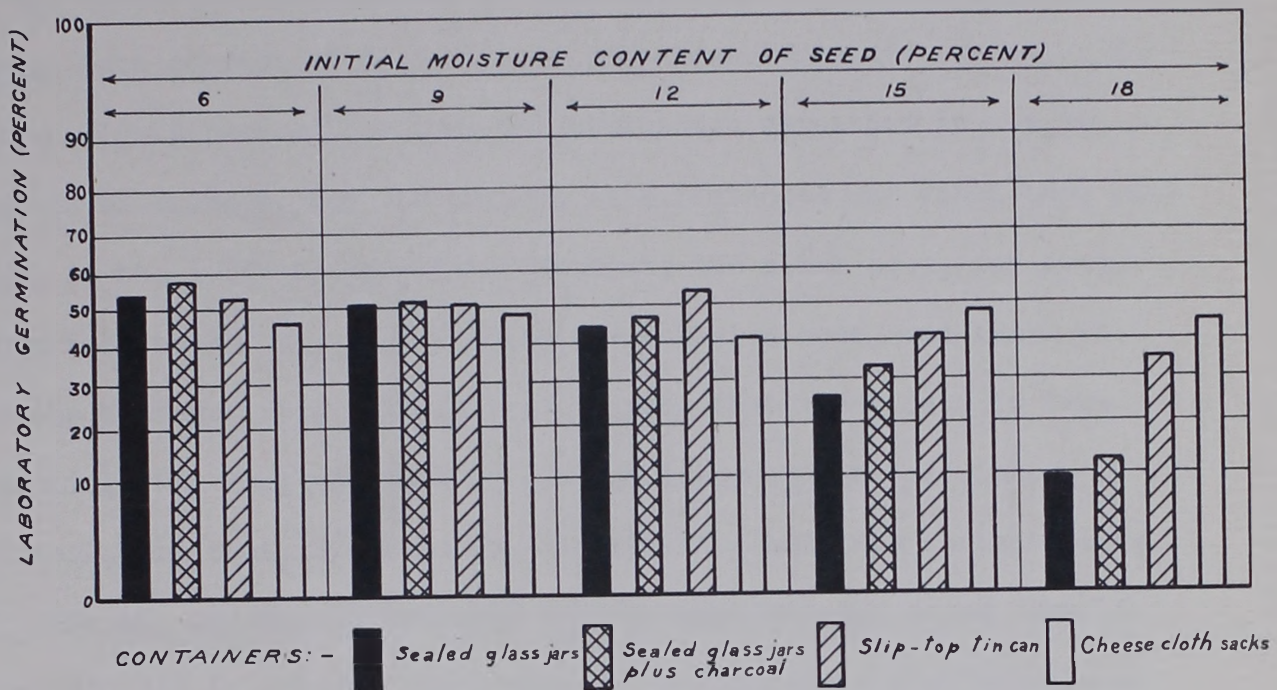
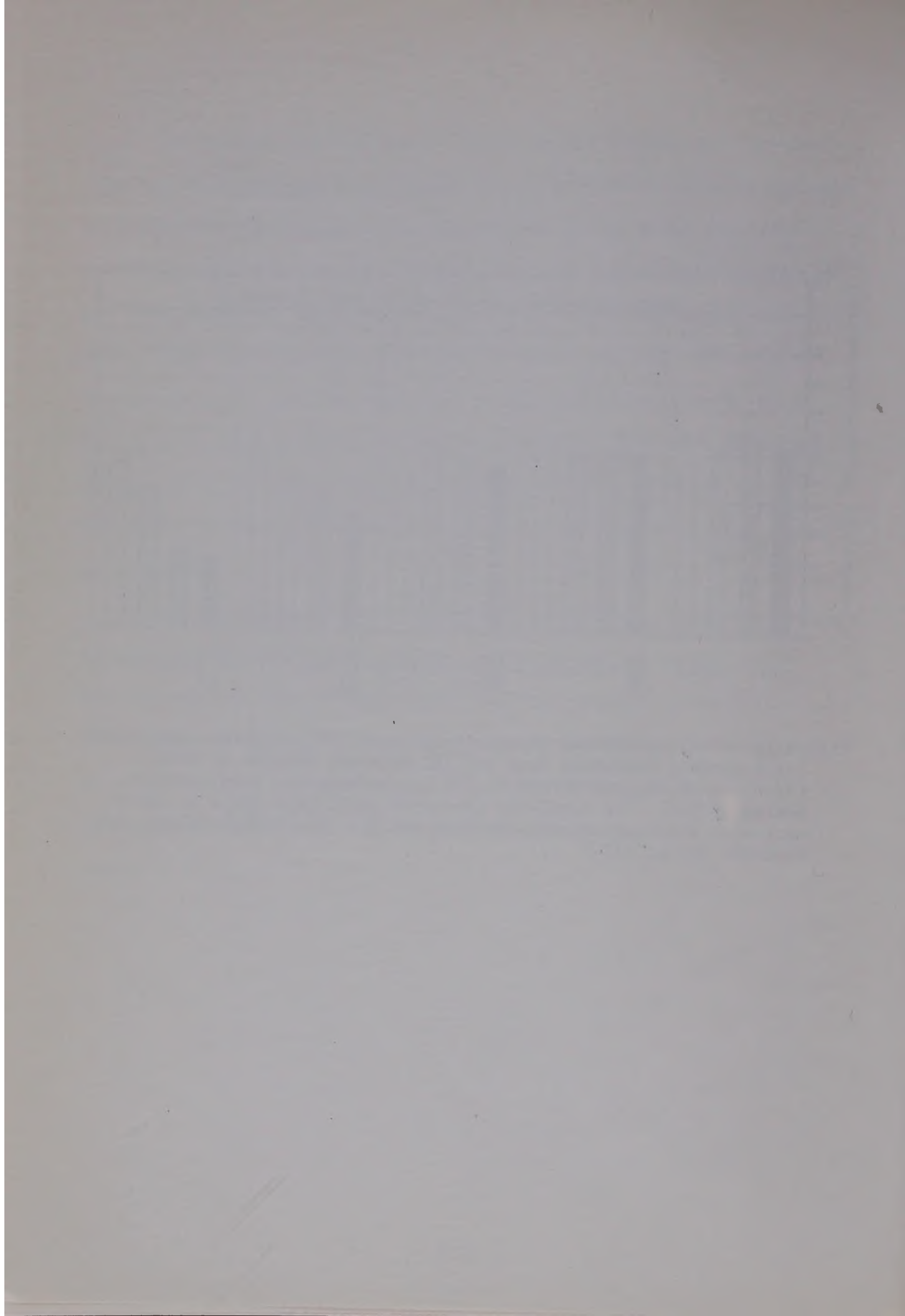


Figure 16.--Varying effects of containers upon 1937 longleaf seed stored 3-1/2 months, depending upon initial moisture content of seed. (Averages of samples stored at 38° F., in unheated shed, and in heated office. The specially graduated percentage scale is necessary when averages are derived from $\arcsin \sqrt{\text{percentage values}}$; see footnote 26, p. 133.)



In a study of slash pine seed from the 1939 crop, closely paralleling the 1937 longleaf overwinter storage study, seed stored at an initial moisture content of 18 percent had a significantly lower laboratory germination percent after $3\frac{1}{2}$ months than did seed going into storage at 6, 9, 12, or 15 percent moisture content. No other significant differences in germination developed in the $3\frac{1}{2}$ months of storage, but the pattern of differences was consistent with that in the longleaf overwinter studies; the slash seed, for example, kept best at 38° F., next best in the unheated shed, and least well in the heated office. These results show that slash seed is less exacting than longleaf seed in its requirements for overwinter storage, but that it should not be held at a moisture content above 15 percent, and should probably be kept considerably drier than 15 percent, and in unheated buildings if refrigerators are unavailable.

Cold Storage Time Schedules

The exact times at which southern pine seed is both placed in and removed from cold storage may be more important than the precise levels of temperature and seed moisture content during storage.

There should be minimum possible delay in placing seed in cold storage. The germinability of extracted seed held at air temperature in unheated buildings, and in moisture equilibrium with the air, may decrease seriously within 4 to 8 weeks (unpublished data). When extraction is delayed too long, germinability may decrease while the seed is still in the cones (p. 95). Even if immediate germinability is not affected, rapid respiration before cold storage depletes the food reserves within the seed. Refrigeration applied later cannot restore the loss, and is therefore less effective than if it had been applied promptly. For these reasons the common practice of holding seed at air temperature until part of it has been sown the spring after extraction, and then refrigerating the rest for use in later years, should be avoided. It is much better to place all the seed in cold storage currently as it is extracted and to withdraw it as needed immediately before sowing. A possible alternative, if refrigerator space is at a premium, is to refrigerate immediately all seed to be held for a year or more and to keep overwinter at air temperature only the minimum estimated amount likely to be sown the spring after extraction.

Removing seed from cold storage and holding it at natural air temperatures or in heated rooms before sowing or testing may be even more harmful than holding it at such temperatures before it has been sensitized (Miller, 1938)(____) by refrigeration. This has been shown most clearly with longleaf pine, which deteriorates significantly within 2 to 4 weeks, especially if at high moisture content (unpublished data), but results with commercial lots of other species indicate that no southern pine seed should be removed from cold storage more than a week before sowing or testing.

Deferring removal in this way ordinarily is simple when seed is stored near the point of use. It may be impossible, however, in shipping seed abroad, especially to the Southern Hemisphere, where the sowing season differs by six months from that in the United States. Rather than expose refrigerated seed to possible high temperatures in transit, it is preferable to arrange export well in advance, ship seed immediately after extraction and cleaning, and keep it in cold storage at its destination from receipt until sowing time.

Miscellaneous Details of Storage Technique

Fungi or bacteria do not seem to affect stored southern pine seed adversely unless other deterioration is already far advanced. Deterioration, as in cotton seed (Altschul, Karon, Kyame, and Hall, 1946)(___), seems to arise mostly from the vital processes of the seed itself. Treating seed with formaldehyde before storage has shown no beneficial fungicidal action. Dusting longleaf seed with a standard organic-mercury fungicide before storage maintained viability no better than in the untreated check and caused abnormal germination like that reported with several other kinds of seed treated with mercury compounds (Brett and Weston, 1941; Leukel, 1948)(___, ___).

Storing seed in sealed containers with suitable amounts of a desiccant such as quicklime (CaO) has kept small samples of southern pine and other seeds at constant, low moisture content percent (Barton, 1935; Barton, 1947)(___, ___), but has not been developed in commercial practice with southern pine seed.

For sealed storage of commercial lots, gasketed grease drums and glass carboys have proved most satisfactory, except that longleaf seed will not pour freely through the narrow necks of the carboys. Burlap or cotton bags are most satisfactory when quick moisture equilibrium with the air in the storage chamber is permissible or desired. Covered ash cans, garbage cans, and shortening cans, although they do not prevent changes of moisture content of the seed inside, delay such changes, particularly if the covers are fastened with wax or tape. Some cans, however, may be sealed, as for overseas shipment, with caulking compound or by soldering.

Samples sent to a seed laboratory for moisture content determination should be placed in screw-topped glass fruit jars, with the covers very firmly screwed down on fresh rubber rings. Samples drawn from cold storage for either moisture content determinations or germination tests, and especially drawn from stratified lots for germination tests, should be sent to the laboratory in tightly corked thermos bottles. Preferably, all such samples should fill the jars or thermos bottles completely.

Sealing charcoal in with seed to absorb moisture and gases has been recommended, especially for overseas shipment. Proper quantities of dry, "activated" charcoal might have this effect and benefit the seed. The available commercial charcoal (such as is fed to chickens) that was used in sealed glass jars in the 1937 longleaf storage study did not significantly increase average survival. In both long storage (table 11) and overwinter storage (fig. 16), the treatment gave less uniform results than sealing the seed in jars without charcoal.

Postponing dewinging until after storage has long been recognized as a means of improving keeping-quality (Baldwin, 1942)(___). Eliason and Heit (Eliason and Heit, "red pine," 1940)(___) emphasize the possible adverse effects of dewinger damage as well as of kiln injuries on stored red pine seed. In the overwinter storage study of longleaf pine seed of the 1936 crop (table 13), the seed with wings attached withstood storage very significantly better than dewinged seed. The U. S. Forest Service regularly stores longleaf pine seed with the wings on, though it usually dewings slash, loblolly, and shortleaf seed before storage.

Recommendations

For storage beyond the first spring following extraction.

Provided seed moisture content can be kept constant after preparation for storage, the seed should:

- a. Be extracted, dewinged (longleaf should be left with wings on), and cleaned with minimum injury;
- b. Be dried to 6 to 9 percent moisture content for longleaf, or 9 to 12 percent moisture content for slash, loblolly, and shortleaf (but see p.123 for completion of drying in refrigerator);
- c. Be placed in cold storage within a week or two after extraction, cleaning, and drying;
- d. Be stored at a temperature not higher than 41° F., preferably at 5° to 32° F.; and
- e. Be removed from cold storage not more than a week before testing or sowing, or before pregermination treatment if such treatment is necessary.

The seed can be maintained at constant low moisture content either by sealing the containers, or by storing it in air-permeable containers in a refrigerator having a constant low relative humidity (fig. 15).

If sealed containers cannot be used and the seed must be stored in a refrigerator too humid to maintain the moisture content at the most favorable level, the seed should be placed in storage at or slightly above the moisture content at which it will come into equilibrium with the air in the refrigerator. Reducing the seed moisture content below this level and letting it rise in storage should be avoided, as should repeated changes in moisture content during storage.

If storage at 41° F. or below is impossible, seed of all species should be kept at 6 percent moisture content in sealed containers at the lowest temperature available; see tables 10, 11, and 12.

For overwinter storage only.

Preferably, seed should be stored overwinter precisely as for longer periods; that is, refrigerated at 41° F. or below, at constant moisture content of 6 to 9 percent for longleaf, or 9 to 12 percent for slash, loblolly, and shortleaf, and otherwise ^{described} as/for long storage.

Second choice, refrigeration at or below 41° F., at constant moisture content not above 15 percent (any species).

Third choice, storage at temperatures as little as possible above 41° F., and at constant moisture content of 6 to 9 percent for longleaf, or 9 to 12 percent for slash, loblolly, and shortleaf.

For shipment abroad, especially to the Southern Hemisphere.

Preferably, ship immediately after extraction and cleaning, in sealed containers, at moisture content of 6 to 9 percent for longleaf, or 9 to 12 percent for slash, loblolly, and shortleaf. Receiver should refrigerate seed at 41° F. or lower (p. 130), at the same or lower moisture content (the latter will necessitate unsealing the containers) from receipt until use.

Second choice (especially applicable to seed already refrigerated before shipment), ship at moisture content similar to the above, either in refrigerated holds or by air express with instructions to keep as cool as possible. Refrigerate from receipt until use.

PREGERMINATION TREATMENTS

Some southern pine seed will not germinate with maximum possible speed or completeness unless it is given special treatment before testing or sowing. This is because, although southern pine seed is inherently capable of prompt and complete germination immediately after maturity, some lots later become more or less dormant--that is, incapable of responding well to even ideal testing or seedbed conditions.

Pregermination treatments may be applied to improve either speed or completeness, or both. In testing, their main purpose is to assure completeness. In the nursery, a treatment that speeds germination may often be justified (p. 220) even if it somewhat reduces completeness. Treatments almost invariably are limited to a few weeks, days, or hours, and must not be extended over long, indefinite periods. They are supplements to storage; attempts to substitute them for correct storage treatments may ruin the seed.

Dormancy

The dormancy of southern pine seeds is simpler than that of some other seeds. Dormant pine seeds have non-dormant embryos and permeable seed coats, and characteristically break dormancy in response to a single chilling while at high moisture content, apparently through improved movement of nutrients and accessory foods from the endosperm into the embryo (Crocker, 1948; Toole, 1939)(__, __).

Seed dormancy seems commonest and most severe in loblolly and shortleaf, less so in slash, and usually negligible in longleaf. It may occur in the most highly viable seed (Barton, 1928; Barton, 1935; Nelson, 1940)(__, __, __) as well as in seed of reduced viability. Apparently it may result from too long drawn out extraction at air temperature, or from extraction in too hot a kiln. As with vegetable seed (Toole, Toole, and Gorman, 1948)(__), it may result either from adverse storage conditions, or from otherwise beneficial drying in storage. Tables 10, 11, and 12 and the text accompanying table 13 give examples of partial dormancy from drying before storage.

Decision as to whether to treat any particular lot of seed for dormancy can best be made after the seed has been received and tested (p. 165). Varying degrees of dormancy are, however, common enough among seed lots in general to require facilities for treatment at all laboratories and most nurseries in which southern pine seed is tested or sown. Methods must therefore be selected and equipment obtained before operations start.

Stratification 27/

27/ The term stratification was originally applied to outdoor storage of layers of hardwood seed between layers of moist sand in pits in the ground (Toumey and Korstian, 1942)(____). Its application to the pregermination treatment described here, in which the seed may be mixed uniformly with the moist medium instead of being kept in strata, is inexact (Society of American Foresters, 1944)(____), but is convenient and generally understood. Throughout this bulletin, stratification is used in the sense of pregermination treatment. Such stratification should never be mistaken for storage (MacKinney and McQuilkin, 1938; Mirov, 1936)(____, ____).

[illegible]

The treatment depends for its success on keeping seed moist but aerated, at a temperature high enough to avoid injury but too low to permit germination, for a period appropriate to the state of dormancy of the particular seed lot.

Temperature.--Despite some conflicting reports (Barton, 1928; MacKinney and McQuilkin, 1938)(___, ___), temperatures between 38° and 41° F. are recommended for stratifying loblolly, slash, and shortleaf pine seed. A temperature of 35° F. probably is acceptable for these species, and is recommended for longleaf pine seed if it needs treatment; at 41° F., longleaf seed sometimes germinates in the refrigerator within a month. The temperature among the seed and intermingled moist medium should never drop below 32° F., lest the seed be injured (Baldwin, 1942)(___). If the relative humidity in the refrigerator is low, rapid evaporation may reduce the temperature of seed and moist medium below that of the air, and cause formation of ice crystals among, or freezing of, the medium and seed. Use of fairly tight (but not sealed) containers, and of refrigerator temperatures of at least 37° F., seem sensible precautions.

Duration.--Several workers (Barton, 1928; Barton, 1935; MacKinney and McQuilkin, 1938)(___, ___, ___), from results with laboratory samples, have advised 2 and 3 months' stratification for all southern pine except longleaf. It seems probable that the samples used by these investigators had become highly dormant from storage in heated buildings. Two- and three-month periods seem most effective with such stubbornly dormant seed lots.

Two- and three-month treatments, however, have been found unnecessary, time-consuming, and inconvenient for most germination test samples, and injurious to some. Practical nurserymen have found these periods unsatisfactory for nursery sowing lots. With such lots, prolonged stratification complicates refrigeration and sowing schedules and increases refrigeration and labor costs. Furthermore, despite the low temperature inside the refrigerator, large masses of seed, unlike laboratory samples, sometimes heat after 2 months or more at high moisture content. Several expensive and irreplaceable lots of southern pine seed have been ruined by such heating. By contrast, some nurserymen have satisfactorily stimulated the germination, especially of longleaf and slash seed, with 20- and even with 15-day treatments. In one instance (unpublished data), 3- and 8-day treatments have effectively broken dormancy of slash and loblolly pine seed, respectively.

From the available evidence, thirty-day stratification is recommended for both germination tests and nursery sowing. Shorter periods may be used where local experience has demonstrated their effectiveness. Because of the danger of heating after longer treatment, stratification of seed lots larger than 5 pounds (dry weight) should be limited to a maximum of 45 days.

Moist media.--Granulated acid moss peat is recommended. Fine quartz sand or sawdust is satisfactory, shredded sphagnum moss somewhat less so. The main requisites are that the medium absorb and hold water well, and not cake, heat, ferment, or decay during treatment. Ease of separation from seed at the end of treatment is an advantage. So is low initial cost, as the material should not be used a second time.

A volume of peat moss, sand, or sawdust at least equal to that of the seed is necessary and two or three times as much probably is best.

Degree of moistness.--Any moisture content above 25 percent of the moisture-holding capacity (not the weight) of the medium is satisfactory (MacKinney and McQuilkin, 1938)(___), provided only that the seeds are not actually submerged in water.

Containers.--If they maintain the moist medium between 25 and 100 percent saturation, nearly any covered containers will do. They should not admit air very freely, lest the medium and seed dry unevenly or too much, but, regardless of size, they should not be sealed. With lots of seed weighing more than 1 or 2 pounds, the containers must be drained. Thirty-gallon ash cans have worked well when equipped with slightly elevated false bottoms of reinforced screen wire or perforated wood. So have wooden sugar barrels with a few small holes in the bottoms.

The larger the seed lots being treated, the more likely they are to dry unevenly, become waterlogged at the bottom, or heat. Large lots should therefore be inspected, remoistened, drained, repacked, or stirred regularly at least once a week.

Mixing and separating seed and medium.--The seed can be kept separate throughout stratification by filling the container with alternate layers of seed and medium, separated by screen wire or thin, coarse cloth. This works satisfactorily if: (1) the layers of seed are never more than $2\frac{1}{2}$ to 3 inches (preferably only $\frac{1}{2}$ to 1 inch) thick; (2) the alternate layers of moist medium are at least as thick as the layers of seed; and (3) the seed, medium, and separators are so arranged that the seed may be inspected, aerated, and if need be stirred and repacked, without difficulty. The most popular method of meeting these conditions, particularly the last, is to place 10- or 20-pound lots of dry seed in cotton cloth sacks large enough to hold double the amounts, immerse them in water to wet the seed, flatten them into disks not more than $2\frac{1}{2}$ to 3 inches thick, and alternate them with layers of moist medium in a drained barrel or can. Putting the same dry weight of seed in each sack permits easy allocation of seed to seedbeds despite gains in weight during stratification.

Mixing the seed uniformly with the moist medium is sometimes more effective than alternating layers of seed and medium. In preparing the seed for treatment, mixing cracked ice with slightly moistened medium and seed chills the entire mass quickly and uniformly, and reduces caking and packing. Such icing has given excellent results, especially with longleaf seed.

The commonest method of separating the seed and medium after treatment in mixture is to dry them till they no longer cling together, and run them through the cleaning mill. Drying should be rapid but gentle, with frequent, gentle stirring. Because of the high moisture content and sensitive condition of the seed, fans should be used instead of artificial heat. Peat or sawdust may be separated from intermingled seed by flotation in running water in a tank or trough, without previous drying. Sand screened before mixing with the seed can be washed out of the seed on the same screen at the end of the treatment.

Sowing stratified seed.--Seed should be sown immediately after separation from the medium. If it must be held overnight, it should be refrigerated at 35° to 41° F. (not lower) to prevent heating, molding, and premature germination. Attempts to redry stratified southern pine seed and store it for even short periods have failed.

Since one of the two main purposes of stratification is to increase germination, sowing rates should be determined from germination tests of treated samples, not of untreated seed. Samples for germination tests may be stratified by: (1) tying lots of 800 to 1,000 seeds in cheesecloth and refrigerating the packets in contact with the moist medium; (2) mixing seed and medium and picking the seeds out individually when setting up the germination test; or (3) setting up the samples in sand flats or on peat mats, chilling seed and flats or mats together for the desired period, and then transferring them to a warm room for germination. The third method requires much more refrigerator space than the other two, but greatly reduces the time required to set up the tests.

Seed at normal moisture content for storage or shipment gains at least 12 percent in weight, sometimes much more, during stratification. This gain correspondingly reduces the number of seeds per pound, and may cause understocking of the seed beds if it is disregarded in weighing out stratified seed for sowing (p. 215).

When seed is separated from the moist medium by fanning or flotation, most empty hulls are removed with the medium. This also should be allowed for in calculating the sowing rate (p.216) of any lot that contains more than 5 percent of empty seed before stratification.

Other Pregermination Treatments

Various studies, and the good results from many commercially refrigerated lots of seed, suggest that a month or more of dry storage at 41° F. or below often suffices as a pregermination treatment. MacKinney and McQuilkin found that loblolly pine seed, after chilling in contact with dry sand and dry granulated peat, as well as after ordinary dry cold storage, increased in rapidity of germination with increasing duration of chilling (MacKinney and McQuilkin, 1938)(___). Tables 10 to 14 show numerous instances of better germination of cold-stored than of fresh seed.

Table 14 shows that the germination of longleaf seed stored $2\frac{1}{2}$ months at low temperatures and high moisture contents was particularly high. The records also show that germination was unusually prompt. The same was true of many lots of longleaf and slash pine seed stored 1 and $3\frac{1}{2}$ months at low temperatures and high moisture contents in studies cited on pp. 145 and 147. These results suggest that soaking the seed to a still higher moisture content and refrigerating it for a still briefer period (20 to 30 days) might be substituted for chilling it in contact with a moist medium. This treatment would save the trouble and expense of the moist medium, but would omit the safeguard of separating individual seeds or layers of seed one from another with inert, moisture-absorbing material, and might cause heating. No such treatment has been tested systematically.

Merely soaking seed (especially longleaf) in water for a few hours or overnight, at air temperature, and sowing without chilling, has sometimes but not always been as effective as stratification. There are indications that, like stratification, soaking may be overdone, and may work well with some lots but be injurious to others. Soaking would be much cheaper and more convenient than chilling in contact with a moist medium, and deserves systematic trial.

Various chemical stimulants (as ethylene gas, thiourea, potassium nitrate, red copper oxide, and zinc oxide) have worked well with seed of other genera but seem not to have been tried with southern pine seed.

Growth-promoting substances--indoleacetic acid, indolebutyric acid, naphthaleneacetic acid, naphthalene-propionic acid, dichlorophenoxyacetic acid, and the like--have been ineffective or harmful on dormant seeds of so many kinds, including those of many conifers (Avery, Johnson, Addoms, and Thomson, 1947; Barton, 1940; Crocker, 1948; Gruenhagen, 1940; Leukel, 1948; Youden, 1940)(____, ____, ____, ____, ____, ____), that they offer little promise of breaking dormancy of southern pine seeds.

There is scant justification for scarifying southern pine seed coats mechanically, or etching them with sulfuric acid. Southern pine seeds absorb water freely without seed-coat modification, and seed-coat treatments seem more likely to injure than to benefit the seed.

Deciding when Pregermination Treatment is Needed

Between 1928 and 1938, severe dormancy of southern pine seed was so common, and stratification so generally improved rapidity and completeness of germination, that it became customary at many nurseries to apply this treatment to all seed lots of all species, except perhaps longleaf. Much southern pine seed still needs stratification or other pregermination treatment, but improved techniques of collection, extraction, and especially of storage have made questionable the arbitrary treatment of all lots. With many, treatment is unnecessary; with some, a simpler, cheaper treatment than stratification may suffice; with some, stratification does more harm than good.

This revised picture of need for and response to stratification was apparent in southern pine nurseries just before World War II. It was confirmed by paired tests of stratified and untreated seed from 18 longleaf, 114 slash, 66 loblolly, and 73 shortleaf seed lots, a total of 271 lots from many different sources (unpublished data). Stratification did consistently speed up germination of these seed lots, and in a few instances did bring about excellent germination of seed that virtually failed to germinate without it. With many samples of each species, however, and particularly of longleaf and slash pine, the gain in rapidity of germination was not great enough to justify the cost of treatment. In a fair majority of the tests, moreover, stratification, instead of increasing total germination, reduced it, often to four-fifths of that of the untreated seed, and sometimes to only one-fifth.

Recommendations

Neither nursery observations nor the tests just cited give any dependable clue as to when stratification is needed or when it will be harmful, beyond the fact that longleaf seldom requires it. Therefore, it is recommended that stratification be applied only to: (a) seed lots that show a beneficial response to stratification in preliminary paired germination tests of stratified and unstratified seed (p. 187); and (b) loblolly and shortleaf seed sown in nurseries in which experience has shown that local conditions render seed of these two species consistently dormant. The same recommendations apply to soaking if that is substituted for stratification.

SEED TESTING

Efficient extractory or nursery operations are practically impossible without good, correctly timed seed tests (Baldwin, 1942; Eliason and Heit, red pine, 1940; Hartley, 1935)(__, __, __).

Control of seed procurement and processing and of nursery sowing rate requires verification of species and geographic race by adequate records, and tests of: (1) numbers or percentage of seed that contain kernels; (2) purity percent; (3) number of seeds per pound; (4) moisture content; and (5) germination percent. These tests need not all be equally precise. At several stages in seed handling, checks or simple tests serve merely to show that changes are proceeding in the right direction, or that seed meets some minimum standard of quality. With such simple tests, frequency and cheapness are more important than exactness--except that sampling must be dependable. Other tests--including practically all germination tests because of their importance in buying and sowing seed and in evaluating seed treatments--must be applied with scrupulous care to meticulously drawn samples.

Access to a specially equipped seed laboratory, with a professional staff (Association of Official Seed Analysts of North America, Committee on Qualifications, 1939)(__) is preferable or essential for the majority of germination tests, particularly at odd seasons and with certain inevitable freakish lots of seed. Without air-conditioned rooms or cabinets, uniform testing conditions are difficult to maintain from month to month and year to year even in such laboratories.

Some useful germination tests can, however, be made with less elaborate equipment at extractories or nurseries by following closely the recommendations in this bulletin. Other tests are preferably or necessarily made at the extractory or nursery (fig. 17). These include purity percent and percentage of full seed during cleaning, moisture content after kiln extraction or artificial drying or before storage, and numbers of seeds per pound after pregermination treatment. Numbers of full seeds per cone must be determined in the field.

Figure 17.--Test of moisture content at U. S. Forest Service extractory, to make sure freshly extracted seed is dry enough for storage. Convection-type electric oven to left is used in determining moisture-free weight for calculating moisture content percent.

Sampling

No seed test is more dependable than the sampling procedure by which the seed to be tested is drawn. For example, sampling without regard to the fact that empty seeds work to the tops of containers has resulted directly in 40 percent lower germination in the laboratory than in the nursery. Sampling which results in discrepancies less than half as serious as this nullifies the most accurate testing technique.

Sound sampling requires that:

1. Seed be drawn at random from the mass to be sampled. Every single seed in the whole lot, and every particle of impurities, should have as good a chance of being taken in the sample as any other seed or particle. There must be no personal bias in the choice of individual seeds or accompanying impurities, as to appearance, weight, position in the mass, or anything else that might affect the results of any test applied to the sample.

2. Drawings be replicated. The entire test sample must not be taken from one part of the seed lot. Instead, separate fractions ("subsamples") of the test sample must be taken from each of two or more different places in the main lot.

3. Sampling be proportional. That is, if natural subdivisions exist in the main lot, as by its being in several containers, subsamples must be drawn from each subdivision. If the amounts of seed in the containers differ, the numbers of subsamples from different containers must be approximately proportional to these amounts.

Sampling good enough for germination tests will be good enough for any other kind of test. Indeed, samples drawn for germination tests ordinarily serve also for determinations of purity percent and of numbers of seeds per pound, and portions of them may be used for moisture-content determinations as well.

Two methods of drawing samples for germination tests are in common use, one for small lots of seed and one for large lots.

The small lot method.--With small lots, the entire mass of seed to be sampled is poured out onto a sheet of paper, a smooth floor, or a tarpaulin, and mixed. The mixing takes care of all three requirements--randomization, replication, and proportional sampling.

The mixing must be thorough. It must be done by scooping or shoveling seed from side to side and from bottom to top of the pile. Shaking the seed in a container is worse than useless, because it moves large seeds, empty seeds, and seeds with wing stubs to the top. The best way to develop judgment of adequate mixing is to add about 5 percent of conspicuously painted and thoroughly dried seeds to the top of a pile and see how much mixing it takes to distribute them uniformly throughout the mass. It takes more effort and time than inexperienced workers realize.

After the seed has been thoroughly mixed, it is built up into a symmetrical, conical pile, which is then flattened into a disc of convenient size and thickness. Approximately half the disc, if the lot is small, or a quarter if it is large, is laid off by eye and separated from the rest of the lot.

This half or quarter is then thoroughly remixed, and in turn heaped up, flattened, and halved or quartered. The process is repeated until the original lot has been reduced to the amount needed for testing.

The large lot method.--With large lots, a sample consisting of many subsamples is drawn from unmixed seed in each of one or several containers, or, less frequently, is drawn from a pile of mixed or unmixed seed without subdividing the pile.

It is recommended that, to avoid waste of time and effort, no samples from large lots be tested unless standards at least equal to the following have been observed in drawing them:

1. Minimum number of subsamples from the seed lot as a whole, 30; more if necessary as indicated under 2.
2. Minimum number of subsamples from each container, 3--one each from the top, center, and bottom thirds of the container. The exact position from which each subsample is taken within each third should be varied as nearly as possible at random from third to third and from container to container, on the principle that all seeds shall have equal chances of being included. A conventional grain probe may be used to sample all species but longleaf, which requires a special probe (p. 539).
3. Minimum number of seeds for subsample, approximately 100, to provide a total of about 3,000 seeds for tests of purity and moisture content, and of germination both with and without pregermination treatment. If for any reason larger subsamples are used, they must be of uniform size.

4. When containers vary greatly in size, a minimum of 3 subsamples must be drawn from each of the smallest containers, and more from the larger in proportion to their size. For example, if part of a large seedlot is stored in 1-bushel and part in 2-bushel bags, 3 subsamples should be drawn from each 1-bushel bag, and 6 from each 2-bushel.

With fewer than 10 containers, the following numbers of subsamples are necessary:

Number of containers:	9	8	7	6	5	4	3	2	1
Numbers of subsamples from each:	4	4	5	5	6	8	10	15	30

These numbers must be adjusted somewhat if containers differ in size, but the total from the whole seedlot must be at least 30.

For purposes of sampling, a single pile of mixed seed should be counted as one container, and subsamples should be taken at 30 equally spaced points throughout the mass. Sampling from the catch-box of the fanning mill, for rough determinations of purity percent and percentage of full seed, is somewhat of a special case, for which 10 or even 5 subsamples may suffice.

With more than 10 containers, the number of subsamples will exceed 30, because at least 3 subsamples are required per container. With a large number of containers the total size of the sample (all subsamples combined) will be greater than necessary for routine tests and may amount to several dollars worth of seed. In such instances the "small lot" method (mixing, heaping, and quartering) is applied to reduce to workable size (3,000 seeds or slightly more) the total quantity of seed drawn by the large lot method.

Although most samples for determining percentage of full seed only, or purity percent only, should be drawn with the same care and refinement as samples for germination tests, there are two notable exceptions.

One is in examining cones for numbers of full seeds, during cone scouting or collection (p. 82). Mixing of cones or sampling from sacks of cones is ordinarily neither desirable nor possible. The requirements of random, replicated, proportional sampling are met well enough by taking one or a few cones from each of several trees, with the greater number from the sizes, ages, and forms of trees bearing the greater part of the crop.

The other common exception is in checking roughly the effectiveness of cleaning to standards (table 9). It is often easier to draw samples from the discharge stream of the mill than from the mass of seed already cleaned. The only precaution necessary is to sample the entire cross-section of the discharge stream. Any one part of the stream may carry a disproportionately high percentage of full seed, empty seed, or impurities. Catching the whole stream in any convenient fine wire tray or basket for a second or two at arbitrary, regular intervals usually gives adequate subsamples. The same method is even more convenient in sampling the trash discharge to make sure excessive sound seed is not being lost.

Sound sampling in accordance with these specifications, plus the equally necessary mixing of the sampled lot before sowing in the nursery (p. 218) costs little if any more than undependable sampling.

Percentage of Seeds that Contain Kernels

With southern pines, only pure seeds, as defined on page 176, are tested for fullness.

Percentage of full seeds is always calculated in terms of numbers, not weight.

$$\text{Percentage of full seed} = \frac{(\text{Number of pure seeds with kernels})}{(\text{Total number of pure seeds})} \cdot 100$$

Calculation of percentage full can be simplified by using 100-seed subsamples, with which the observed number of full seeds equals percentage full, or 25-seed subsamples, with which multiplying observed number of full seeds by 4 gives percentage full.

Within the limits of accuracy of the sampling method, the percentage of full seed shows the maximum germination percentage that can be attained by the seed lot. Whether the germination closely approaches this maximum, or falls considerably below it, depends largely on the previous treatment of the seed. Percentage of full seed may be used to determine rate of sowing (Read, 1932)(____), as described on page 216, but calculations based on actual germination percent are more reliable (Baldwin, 1932)(____).

After final cleaning, before purchase, between stratification and sowing, and especially in examining the seeds left at the end of a germination test, cutting the seeds with a sharp knife, because it also permits distinguishing sound from spoiled kernels, is the best way of finding out whether seeds are full. A soft board with 25 or 100 conveniently spaced dents to hold the seeds greatly simplifies both counting and cutting. Hard seeds like loblolly or small ones like shortleaf can also be cut conveniently on the sticky side of an adhesive tape.

When sound and spoiled kernels need not be distinguished, laying counted subsamples out on a hard, flat surface and smashing each seed with a hammer (Read, 1932)(____) is quicker than cutting. Full seeds crush into oily paste studded with bits of seed coat; empty ones into dry fragments. This is the preferred method for checking percentage of full seed during cleaning.

In determining full seeds per cone to see whether cones are worth collecting or whether collection quotas must be increased, usual practice is to cut sample cones lengthwise with a sharp knife and estimate roughly the number of full seeds in each. Prying the seeds out of a few cones with a screw driver or with long-nosed pliers ground to chisel points, cutting the apparently sound seeds, and comparing the numbers of full seeds with those revealed by cutting other cones from the same trees, is the best way of learning to make such estimates.

Purity Percent

Pure southern pine seed consists of all fully formed, apparently normal seeds regardless of whether they contain kernels. All dwarfed, malformed, pitchy, broken, and visibly cracked or wormy seeds are included with trash as impurities. This standard, though more exacting than that ordinarily applied to agricultural seed (U. S. Production and Marketing Admin. 1946)(___), is justified because it permits a more accurate forecast of seedbed germination than is possible if variable numbers of visibly injured seeds are assumed to be good. Detached seed wings are impurities, but wings or wing stubs that still adhere are included as parts of the seeds.

$$\text{Purity percent} = \frac{(\text{Weight of all apparently normal seeds in subsample})}{(\text{Total weight of subsample})} \cdot 100$$

These standards and this method of computing purity percent are essential to the rate-of-sowing formula on page 216. Calculation usually is carried to the nearest 0.1 percent. Balances accurate to 0.1 gram are sensitive enough with fairly large subsamples; balances accurate to 0.01 gram permit using smaller quantities of seed.

In buying seed or deciding on rate of sowing, purity percent is conveniently determined from samples drawn for germination tests. The germination test is then made with random subsamples of the pure seed segregated in determining purity.

For rough determinations of purity during cleaning, samples are usually drawn from the mill discharge (p. 174) or from the catch-box by the "large lot" method, but with only 5 to 10 subsamples instead of 30. The cleaning process should be adjusted until 5 to 10 successive subsamples taken at brief intervals give fairly uniform purity percents averaging at least as high as the desired standard. Sampling should be repeated frequently to see that the standard is being maintained.

For precise determinations of purity percent, 8 to 10 subsamples per seedlot should give a good average and a satisfactory estimate of reliability; 4 or 5 may be enough if the seed is very clean and has been well mixed. Ten-gram subsamples are about the minimum acceptable for well-cleaned shortleaf, loblolly, and slash seed, 15-gram for dewinged longleaf, and 20-gram for longleaf with wings intact. Subsamples double or triple these sizes may be necessary if balances accurate to only 0.1 gram are used, if only 4 subsamples are examined, if the percentage of impurities is high, or if large impurities such as cone scales are present.

Even for rough determinations, the weights of each of the 4 or 8 subsamples used to compute average purity percent should be nearly identical. Averaging the purity percentages of subsamples differing greatly in size may seriously distort the average unless it is obtained by weighing.

Number of Seeds Per Pound

The common way of finding the number of seeds per pound is to divide 453,600 by the weight (to the nearest 0.1 gram) of each of 4 or 8 random subsamples of 1,000 apparently normal seeds apiece. The subsamples are usually counted out from the pure seed segregated in determining purity percent. The subsample values are averaged to find the number of seeds per pound for the lot.

Four subsamples may be enough to show the reliability of their average if the individual determinations do not vary more than two or three percent in weight per thousand seeds, or if no very exact result is needed. Eight subsamples are needed if results are variable and a close estimate of the average for the entire seed lot is desired.

The 1,000-seed subsample is arbitrary. With good sampling and eight subsamples, 200- to 500-seed subsamples of any species are practically as reliable if weighed to the nearest 0.01 gram (0.1 gram for longleaf seed), and are far cheaper to count. The weights of subsamples of less than 1,000 seeds each are converted to seeds per pound by the formula:

$$\text{Number of seeds per pound} = \frac{(453.6)(\text{Number of seeds in subsample})}{(\text{Weight of subsample in grams})}$$

Since counting, and not weighing, is usually the main source of error or of excessive cost, it should be done only by conscientious individuals provided with good light, comfortable temperature, and ample table space at comfortable height.

Seeds should not be counted singly, but in twos and threes to make tens. The number of tens should be verified before they are combined into piles of 100; in like manner, the number of piles of 100 should be checked before combining into subsamples of 200, 500, or 1,000 seeds. Alternatively, to save mental fatigue, seeds can be counted out by sliding them onto any desired number of small spots, on stiff paper.

Moisture Content

Seed moisture content is most conveniently expressed as a percentage of the oven-dry weight of the seed, calculated by the formula:

$$\text{Moisture content percent} = \frac{(\text{Original weight}) - (\text{Oven-dry weight})}{(\text{Oven-dry weight})} \cdot 100$$

Moisture content percent is almost invariably based on random subsamples of seed plus accompanying impurities. It is usually recorded to the nearest 0.1 percent.

Authorities differ as to the best method, direct or indirect, for determining seed moisture content (Baldwin, 1942; Barton, 1935; Toole, germ. equip., 1939)(____, ____, ____). The Southern Forest Experiment Station dries subsamples in electric ovens maintained at 101° to 102° C. (about 214° to 216° F.) by thermostats. Convection-type ovens (fig. 17) cost less than forced-draft ovens, but the latter dry seed more quickly and may be preferable where the moisture contents of many seed lots must be determined almost simultaneously to insure optimum storage.

The subsamples are oven-dried until repeated weighings show no appreciable further loss in weight. Such drying usually takes 4 to 12 hours, rarely 16 to 24. Drying is quicker in wire containers than in glass, tin, or paper. The process should not be continued beyond the attainment of constant weight lest chemical changes in the seed result in further reduction of weight not due to loss of moisture.

Since moisture content determinations involve no separating, counting, or cutting of seeds, increasing the size of the subsample adds to the cost mainly by using up more seed. For most seed lots, subsamples should weigh 20 to 100 grams apiece. Ten grams should be a minimum even with small seed lots; subsamples of 200 grams (not quite $\frac{1}{2}$ pound) apiece may be desirable with seedlots weighing several hundred pounds. At least two subsamples should be tested from each seed lot. Four to eight are preferable for lots of several hundred pounds, or for any lots the moisture contents of which must be known precisely.

As the moisture contents of small quantities of seed change very rapidly in response to atmospheric humidity, the original weights should be recorded immediately after the subsamples are drawn from the main seedlot. The only workable alternative is to seal the subsamples in separate jars, with a minimum of air space, until weighings can be made.

Germination Tests

To date, direct tests have proved by far the most generally feasible and reliable means of learning the germination percent of southern pine seed. Indirect tests which depend upon dissecting or cutting and staining the seeds or employ other rapid methods (Baldwin, 1942; Crocker, 1948; Eidmann by Godfrey, 1936; Flemion, 1948; Flemion and Poole, 1948; Hao by Rudolf, 1939; Mirov, 1936; Porter, Durrell, and Romm, 1947; Shafer-Safonova, Kalashnikora, and Kostromina by Shirley, 1934)(____, ____, ____, ____, ____, ____, ____, ____, ____, ____) have not been adapted to large-scale differentiation of living from dead southern pine seeds or to the differentiation of normally from abnormally germinating seeds.

A direct test of the germination of southern pine seed must provide correct amounts of four things--moisture, oxygen, warmth, and light. No seed can germinate without the first three. Some lots of southern pine seed can germinate without light but, since many require light for optimum germination (fig. 18), the only safe rule is to provide light for all. Inadequate moisture and excessive temperatures probably are the most frequent causes of poor germination of test samples, but some of the most serious failures have resulted from testing in dark chambers or under covering which light could not penetrate.

Figure 18.--Germination of southern pine seeds in total darkness or dim light, contrasted with that in normal diffuse daylight.

It is recommended that for each seed lot, regardless of size, germination be recorded separately for 8 subsamples of 100 seeds apiece. This procedure insures the minimum dependable samples for large lots, together with the most useful analyses of results (pp. 192 to 193) from all lots.

The medium on or in which the subsamples are tested is the principal means of controlling the moisture and oxygen supplied to the seed. Both fine quartz sand and compressed mats of granulated acid moss peat have given better results with southern pine seed than have filter paper, blotting paper, paper towels, sawdust, porous clay plates, soil, and mixtures of sand with soil or peat.

Sand flats vs. peat mats.--Sand requires less skill and less special equipment than peat mats, and may be easier to get. It is safe if uninfected with damping-off or other harmful fungi and if kept moist, but must be sterilized with formaldehyde (p.528) or by washing thoroughly with water at 158° F. or higher (Dunlap and McDonnell, 1939) (___) if infection is found or suspected. Even in inexperienced hands, sand flat tests are likely to forecast nursery germination reliably because seeds germinating weakly or abnormally usually fail to emerge from the sand (Eliason and Heit, red pine, 1940)(___). The chief disadvantages of sand are its weight, the difficulty of keeping it at optimum moisture content (flats must be watered at least once a day), and its tendency (unlike peat moss) to get into laboratory apparatus. Sand is best used in greenhouses or special germinating rooms. Sand may be used in flower pots (Dunlap and McDonnell, 1939)(___), but shallow, square "flats" save table space.

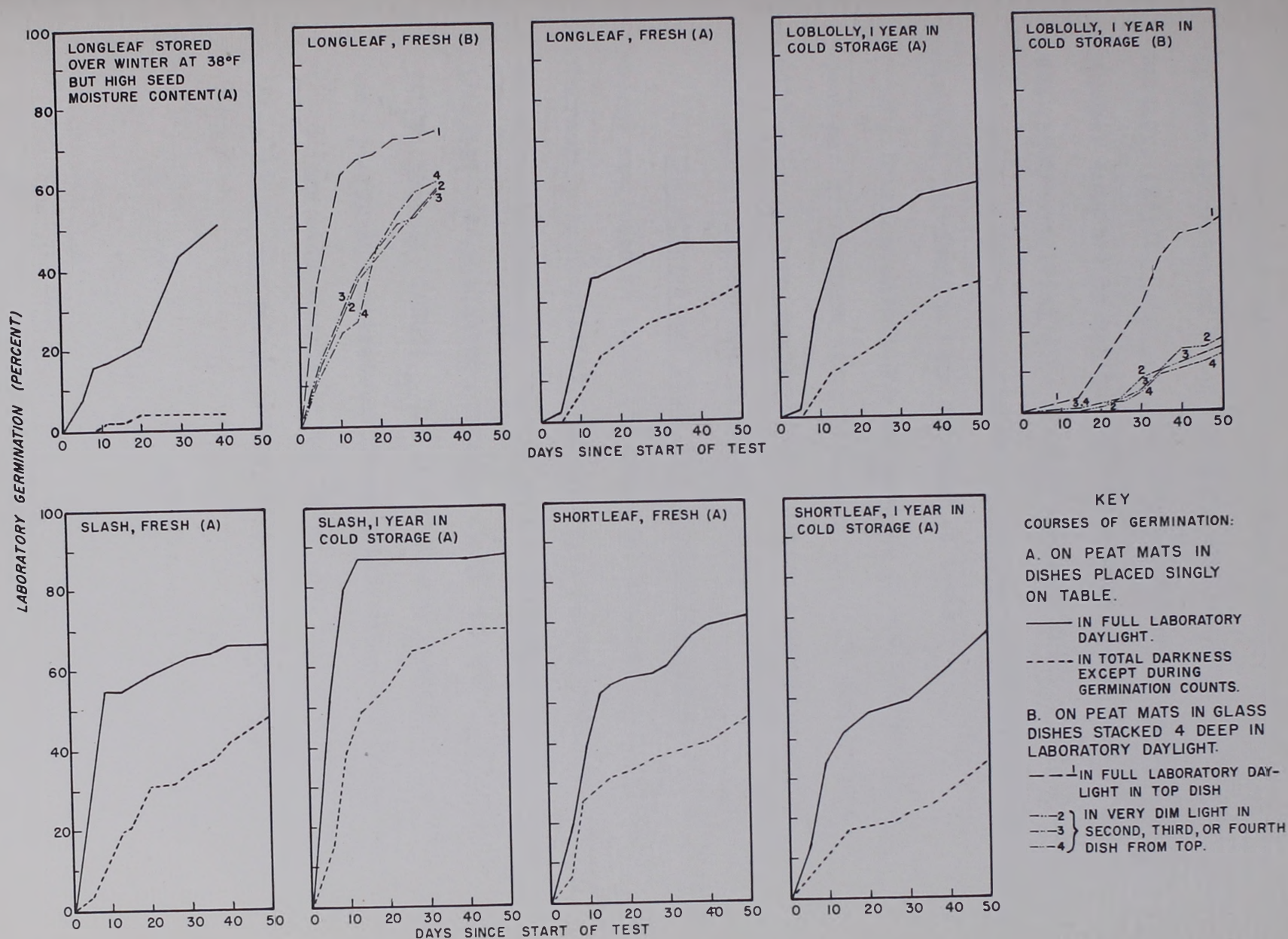


Figure 18.--Germination of southern pine seeds in total darkness or dim light, contrasted with that in normal diffuse daylight.

Granulated acid peat is superior to sand in many ways, especially when economies of labor and space are important (Wakeley, 1932; Wakeley, 1935)(____, ____). Its greatest advantage is the ease with which correct moisture is maintained. Once well established, peat mats seldom require watering more often than every fifth to tenth day. Peat mat tests, however, require more training and experience to distinguish abnormal germination than do sandflat tests.

Detailed directions for setting up and conducting sand-flat and peat-mat germination tests are given on p.543. Either flats or mats will maintain very nearly ideal moisture conditions and oxygen supply if these directions are followed exactly.

Temperature and light for germination tests.--Of the temperatures suggested in table 15, those for longleaf pine have been most thoroughly substantiated. In nature, longleaf seed germinates in November and December. During stratification in the refrigerator, longleaf has germinated gradually at 41° and fairly rapidly at 50° and 59° F. (Barton, 1928)(____). It germinates readily at 60° to 75° but very poorly at temperatures continuously above 80° (McCully, 1945)(____), and wide experience has shown that even a few brief periods above 80° F. may delay, reduce, or prevent germination.

The room or incubator in which the sand flats or peat mats are placed is the principal means of controlling temperature and light, although sowing seeds too deeply in sand, or placing peat mats one upon another (fig. 18) may nullify the effect of good light. The other southern pines germinate better than longleaf at temperatures slightly above 80° F., and their germination may be retarded or prevented by low temperatures at which longleaf germinates well. So far as is known, seed of any southern pine benefits by some day-to-night fluctuation in germinating temperatures.

Temperatures considerably higher or lower than optimum probably account for some of the inconsistencies in long-time storage tests, in which an additional year's storage has seemed to improve the quality of the seed (tables 11 and 12)(Barton, 1935; Mirov, 1936; Roe, 1948) (____, ____, ____). The same unsuitable temperatures that have caused inconsistent germination of stored seed must also have distorted the results of some germination tests made as guides to nursery sowing. Such difficulties can be overcome only by learning the optimum germinating temperatures of all species and maintaining them during the germination tests (Barrett, 1946)(____).

Table 15.--Suggested temperatures 1/ for germination tests of southern
pine seed

Species	Recommended limits		Assumed best	
	Minimum	Maximum	Constant	Fluctuating
	----- Degrees Fahrenheit -----			
Longleaf	40	80	70	60 - 75
Slash	55	85	75	65 - 80
Loblolly	50	85	75	65 - 80
Shortleaf	45	85	75	60 - 80

1/ Measured in the air just above the germinating medium.
Evaporation from the surface of the medium usually cools the seed
to a level slightly below that of the air.

Eight or ten hours' exposure each day to normal diffuse daylight (bright enough for reading fine print) gives southern pine seeds in correctly sown sand flats or on peat mats all the light they need. Exposure to equally intense electric light from either incandescent or fluorescent bulbs, for like periods, apparently (unpublished data) gives just as good results. The lower limits of safe illumination are not known, but must vary considerably as some lots germinate less well in dark corners than near a window, whereas occasional lots germinate satisfactorily in total darkness. Direct sunlight dries out sand flats too fast and makes dark-colored, glass-covered peat mats dangerously hot.

Injuries and abnormalities.--Some mold invariably develops in tests on peat mats--it starts on dead and empty seeds--but usually may be disregarded (Fisher, 1941)(____). Special techniques to control mold (Allen, 1947)(____) are not necessary with southern pine seed of reasonably high vitality. Sterilization of the seed with calcium hypochlorite, sometimes recommended, may do more harm than good (Spaeth and Afanasiev, 1939)(____).

The larvae of fungus gnats sometimes attack first the mold and then the seeds in peat mat tests, and seeds in sand. This ordinarily occurs only when temperatures are unfavorably high, and mostly in greenhouses open to outside air. On peat, the maggots seldom harm the germinating seeds until they have eaten most of the mold.

Germination may be abnormal, usually as a result of injury during extraction, dewinging, or storage (Eliason and Heit, red pine, 1940; and unpublished data)(____, and unpublished data). In sand flats, seeds germinating abnormally seldom appear above the sand, but on peat mats care must be taken not to confuse them with normally germinating seeds. A few southern pine seeds contain two or more embryos, of which one is usually normal in size and the others dwarfed, though occasionally there are two of normal size (Nelson, 1941)(____). Instructions for recognizing and recording normal, abnormal, and polyembryonic germination are found on p. 552.

Scheduling germination tests.--Tests must be started early enough to allow time for complete or nearly complete germination before the date of sowing, yet not so early that the main lot of seed will have time to deteriorate or become dormant between testing and use. The viability of good, correctly stored seed ordinarily remains constant for the periods required for testing by the techniques described--usually 25 to 35 days with non-dormant seed and 40 to 50 days (including 20 to 30 days' stratification) with dormant seed.

With the exception, usually, of longleaf, scheduling of germination tests for calculating sowing rates is complicated by the possibility that any seedlot may require stratification before nursery sowing, but that the need for such treatment cannot be recognized in advance of germination tests (p. 165). The problem introduced by stratification is solved by starting tests 45 days before the contemplated dates of sowing, and reporting results as scheduled in table 16.

Table 16.--Approximate schedule for paired germination tests of untreated and stratified seed, to determine sowing rates

Steps	Comparable parts of sample	
	Tested	Stratified
	without	before
	stratification	testing
	Days after receipt of seed	
Part of sample stratified	...	1
Germination test started	1	30
First report to nurseryman <u>1/</u>	15 to 18	40
Second report to nurseryman	25 to 30	45
Final report to nurseryman <u>2/</u>	40 to 50	50 to 55

1/ If low germination suggests seed is dormant, nurseryman should be advised immediately to stratify lot from which sample was drawn.

2/ With results of cutting test of ungerminated residue.

Some germination tests for special purposes must be scheduled independently of sowing date. Tests designed to forestall or eliminate injuries to seed during extraction and dewinging, for example, must be started at intervals during these processes (p. 113). Seed lots to be stored for long periods should be tested by means of samples, both stratified (except possibly with longleaf) and unstratified, drawn a week or less before placing the lots in storage. Other samples may be drawn annually to see how the seed is keeping. August or September tests of stored seed are highly desirable as guides to collection of fresh seed, but because of the temperature requirements (table 15) cannot be made in the South without temperature control facilities. None of these special-purpose tests can ordinarily be substituted for those made to control sowing.

Reporting and Interpreting Results of Seed Tests

The report of any seed test should be explicit and detailed enough to permit duplication of the test by a competent technician (Lawrence, Lawrence, and Seim, 1947)(___).

The report should include sampling method, size of sample, number and size of subsamples, testing technique used, and results separately by subsamples. The report of a germination test should record also the arrangement of subsamples in sandflats or other apparatus (for use in statistical analysis) and duration and calendar dates of test, as well as nature, duration, and calendar dates of any pre-germination treatment applied. In well standardized work, such records may be shortened by explicit references to written specifications kept in accessible files and followed exactly in testing. When techniques are varied from sample to sample, they should be recorded individually in the reports.

Omitting any of the foregoing details may make test records very misleading. Many a sparse seedbed has resulted from sowing old, partly deteriorated seed at a rate computed from an undated record of germination thought to be recent but actually determined when the seed was fresh. Other lots of seed have been similarly over-rated because high percentages of seed have been reported as "good" without noting that the percentages had been determined by hammer test instead of by actual germination.

The interpretation of germination tests usually involves one step beyond the simple averaging of subsample results required in all seed tests. This step is deciding the extent to which the observed germination may be effective in nursery practice. In southern pine nurseries, germination is effective only if it takes place within a short period--generally 2 or at most 3 weeks--and is most effective if this period begins very soon after sowing. If germination takes long to start, the seed is unduly exposed to birds and to pre-emergence damping-off. If germination, once started, is spasmodic and long-drawn-out, the first seedlings to emerge are likely to be smothered by the seedbed cover (especially a cloth cover), and the last, to succumb to drought or heat after the cover has been removed.

The easiest and most practical way of judging effective germination from the test of a representative seed sample is to note the "shoulder" at which the curve of total germination flattens off after a rapid rise (fig. 19). Germination taking place after the curve has begun to flatten off may be discounted; any trees resulting from such belated germination will be too few to crowd the beds. Seeds germinating abnormally should be excluded from the curve, as they almost never produce trees.

Figure 19.--Percentages of effective germination indicated (where recognizable) with arrows on curves of total normal germination. A, unstratified longleaf seed; B and C, initially dormant slash seed, stratified and unstratified; D and E, initially dormant loblolly seed, stratified and unstratified, respectively.

If the seed was of high viability and was non-dormant (either naturally or from pregermination treatment), germination will have started and ended rather abruptly. In such instances the shoulder of the germination curve is conspicuous, and marks plainly both the level of effective germination and the days required to attain it (fig. 19, A, B, and D). After a preliminary delay, even dormant seed may have exhibited moderately quick germination which terminated abruptly enough to permit a shrewd estimate of effective germination (fig. 19 C). In either case, the presumption is that germination in the nursery will parallel that in the laboratory (p. 215), though perhaps at a somewhat lower level because of less uniformly good germinating conditions in the seedbed (p. 140).

If germination during testing was spasmodic or long-drawn-out, the germination curve may show no distinct shoulder (fig. 19 E). In such an event, more elaborate calculations of "germinative energy," although possible (Baldwin, 1942; Toumey and Korstian, 1942)(____, ____), seem of doubtful value. Indeed, it may be questioned whether the seed, in the condition in which it was tested, was capable of effective germination.

Curves of total normal germination over days of test are most easily plotted from germination recorded as recommended on page 552 . An experienced seed tester or nurseryman can often determine effective germination merely by inspecting the laboratory record.

The germination of a seed lot in the nursery seldom is exactly the same as that of the corresponding test sample. For this reason, the usefulness of the germination test may be greatly increased by calculating the upper and lower limits between which the germination percent of the main seed lot is likely to fall. These limits may be used to estimate the maximum and minimum numbers of seedlings per square foot that are likely to result from any given rate of sowing in the nursery. It may also be important to know whether the difference between the average germination percentages of two test samples is attributable to differences in seed treatment, or to chance. Comparisons of this kind are invaluable in developing improved methods of extraction (Rietz, 1941)(____), dewinging and cleaning (Eliason and Heit, red pine, 1940)(____), and storage.

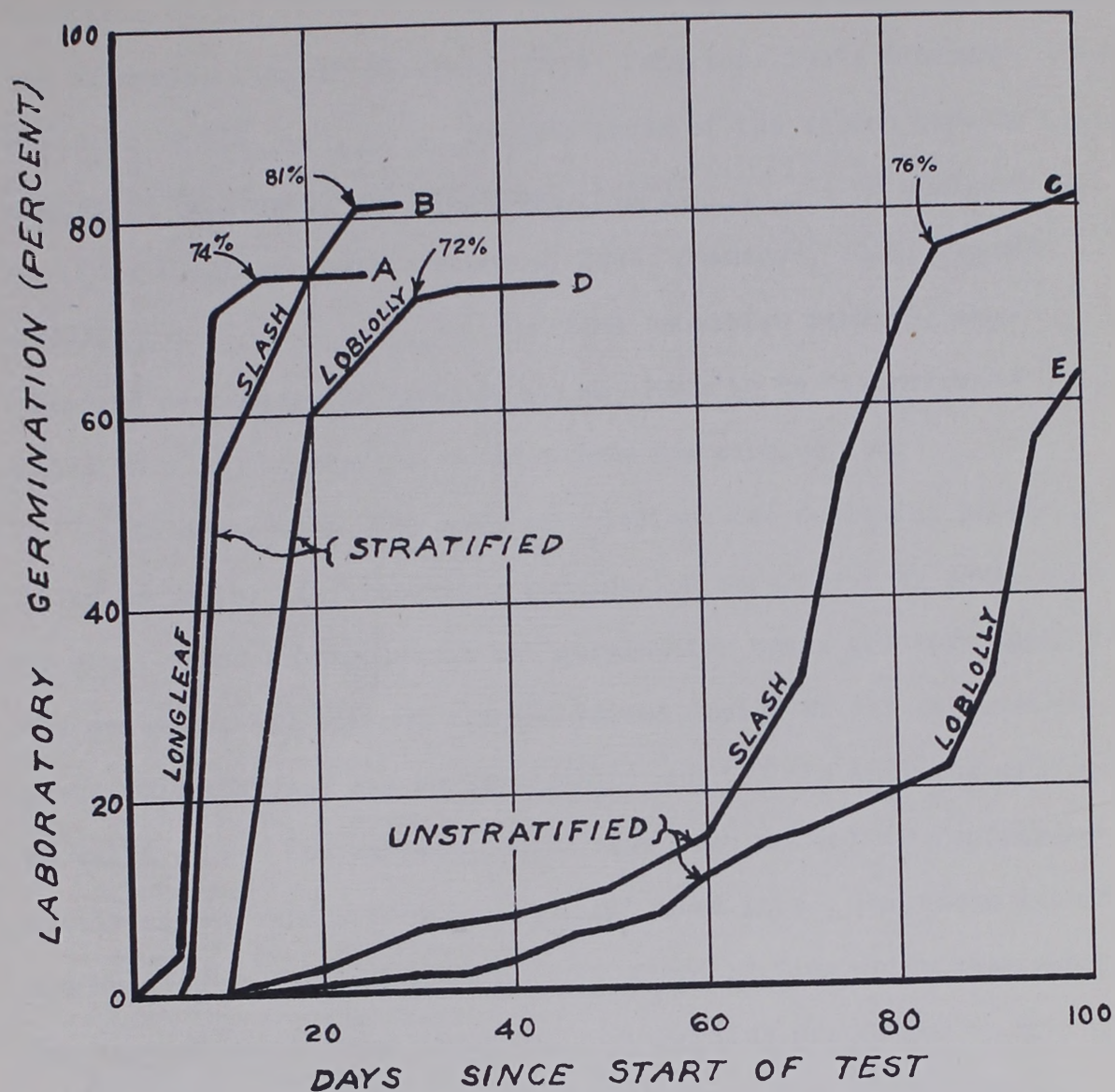


Figure 19.—Percentages of effective germination indicated (where recognizable) with arrows on curves of total normal germination. A, unstratified longleaf seed; B and C, initially dormant slash seed, stratified and unstratified; D and E, initially dormant loblolly seed, stratified and unstratified, respectively.

Questions of the first of these two types may be answered by calculating "fiducial limits" (Goulden, 1939; Paterson, 1939; Snedecor, 1946; Tippett, 1937)(__, __, __, __); those of the second type by "rank-analyses" (Wilcoxon, 1947; Wilcoxon, 1947)(__, __) or analyses of variance (Goulden, 1939; Paterson, 1939; Snedecor, 1946; Tippett, 1937)(__, __, __, __). For most sensitive results, each observed percentage of germination may have to be "transformed" as noted on p.133 before the calculations are carried out.

In connection with such calculations the following points require emphasis: (1) recording germination separately by equal numbers of equal-sized subsamples in all germination tests greatly simplifies the analyses; (2) without a standardized design of all germination tests, the analyses may be impossible; and (3) the analyses will not be valid unless the samples tested have been drawn both representatively and at random from the original seed lots. For these reasons, and because it is impossible to know ahead of time which test results may require statistical analysis, the sampling procedures on pp. 168 to 174, the use of 8 subsamples of 100 seeds each in all routine germination tests, and the detailed records described on p. 552, are recommended.

SEED COSTS, PURCHASES, SALES, AND RECORDS

Southern pine seed costs are so variable that average costs have little meaning. Over a 5-year period before World War II, southern pine seed cost the U. S. Forest Service from \$0.21 to \$2.72 per thousand trees planted, and made up from 3.4 to 18.6 percent of the total cost of planting (table 5). Prewar prices per pound, at different times and places, ranged from \$0.22 to over \$25.00.

The extent of the market for seed is also hard to describe. About all that can be said is that just before World War II the U. S. Forest Service alone used at least \$40,000 to \$50,000 worth of southern pine seed a year (Anonymous, planting charts, 1941; Cossitt, 1940; Gross, 1939)(__, __, __); that post-war demand by all agencies in the southern pine region has risen to \$150,000 worth a year, or more; and that foreign demand has been considerable and seems likely to remain so (Mattoon, 1936; Sherry, 1947; Troup, 1932)(__, __, __).

Costs

With even moderately good equipment and technique, extraction and cleaning costs are fairly constant. They can be kept low; in efficient plants, before World War II, these costs together seldom exceeded 30 to 50 cents a pound, including depreciation of buildings and equipment. Exact data are scanty, but indicate that from 60 to 95 percent of the total cost per pound is for collection, including transportation. Seed cost accounts that itemize scouting, collection (or purchase), shipment, extraction, and cleaning, and any subsequent storage, pregermination treatment, and recleaning where these are necessary, are the most useful guides to reduction of total cost per pound.

In the final analysis, however, cost of seed per thousand trees produced, rather than cost of seed per pound, is the proof of economical seed collection, extraction, and storage. Seed collected at low cost in a good seed year and maintained at a uniformly high level of vitality by cold storage at low moisture content may cost considerably less per thousand trees planted (even allowing for storage charges) than fresh seed collected at high cost in a poor seed year. The opposite may be equally true; cheap seed weakened by poor storage may cost far more in the end than fresh, vigorous seed collected at high prices. At comparable high levels of vitality, small seed at a high price per pound is cheaper than large seed at a low price. In table 5, for example, the average cost per pound of shortleaf seed doubtless was considerably higher than that of longleaf seed, but the average cost of seed per thousand trees produced was only a third as much.

Because it costs more per thousand to water, weed, spray, and lift seedlings in sparse stands than those at normal seedbed density, seed injuries, by reducing the density, frequently increase nursery costs per thousand trees as they do outlay for seed (fig. 10). Any minor saving in labor, supervision, or equipment at the expense of seed vitality is therefore false economy.

Buying and Selling Seed

The principal American users of southern pine seed have been Federal and State agencies and large industrial concerns. They have obtained seed in various ways and have often changed methods from year to year. The result has been an unorganized and erratic seed trade, which has been unable to make full use of existing technical knowledge.

Decentralization of seed collection is essential to meet the needs for local seed for the innumerable planting programs scattered throughout the southern pine region. Decentralization can be attained with greatest benefit to all concerned by developing a steady trade with local collectors. Conscientious, well-informed men living in the many areas from which seed is wanted, and collecting cones year after year, can supply seed of more suitable geographic races than can collectors concentrated in a few places only. Usually with substantial profit to themselves (Bryan, 1943)(___), they can supply it at lower cost than can inexperienced local crews hastily recruited by some outside agency or flying squadrons sent into collecting grounds from a distance.

Experience both in the South and elsewhere (Baldwin and Shirley, 1936)(____) has shown that local collection of cones is encouraged by: (a) planning of planting, and of the necessary seed procurement, for several years in advance, so that advantage can be taken of abundant seed crops; (b) systematic purchasing from considerable numbers of local residents whenever cone production permits collecting at reasonable cost; and (c) full use of forestry and extension field organizations to bring collectors and purchasers together and to inform collectors concerning techniques. Development of small, cheap, dependable extracting plants would also improve the seed trade by enabling more local collectors to extract seed effectively from the cones they collect.

General agreement as to maximum moisture contents (pp. 111 and 152) and minimum purity and full seed percents (table 9) at which seed should be weighed, stored, shipped, and sold would also benefit the seed trade.

Six of the most prolific sources of trouble in selling or buying cones or seed are:

1. Speculative collection (that is, without orders in advance) in excess of assured markets.
2. Failure of the buyer to make clear that an inquiry concerning quantities or prices of cones or seed is not an order.
3. Placing of orders during or after, instead of well before, the collection season.

4. Deterioration of cones through delayed or improper shipment (p. 93).
5. Failure of the buyer to specify the maximum quantity of cones or seed he will accept at a specified price. (This sometimes leads collectors to deliver many times the quantity the buyer can accept, and his refusal invariably leads to hard feelings.)
6. Weighing seed without considering its moisture content. Under extreme conditions 100 pounds of long-leaf pine seed shipped at a moisture content of 35 percent may dry to 8 percent in transit and hence weigh only 80 pounds on arrival. Smaller losses of weight than this may jeopardize business relations if the cause is not understood.

These and other difficulties can be avoided by entering into a written contract for cones or seed after the collector has scouted for cones but before the collecting season has opened. Trouble can be avoided by never collecting from another's land without first getting written consent. Some agencies require proof of ownership before they will accept delivery of cones.

A contract for cones should state plainly:

- a. The species, quality, and cleanness of cones that will be accepted; locality of collection; degree of maturity to be attained before collection; and care to be given cones until delivery.

- b. The unit of measurement. Sale by the bushel of unopened cones is much fairer than sale by weight, since weight changes rapidly during the collecting season.
- c. Price per unit and time of payment. Often it is desirable to pay for cones weekly or biweekly, to enable the collector to pay his crew. The contract should also specify who is to furnish, who pay for, and who keep the bags.
- d. Point of delivery, and frequency of shipment by collector or of pickup by buyer (at least once a week, and preferably oftener, to prevent deterioration in the sacks).
- e. Time and place of inspection, persons to make the inspection, and bases for accepting or rejecting cones.
- f. Largest quantity the buyer will accept at the contract price. A penalty clause for non-fulfillment of the contract by the collector may also be included, but because of the difficulty of estimating accurately the quantity of collectible cones the clause should not force delivery of more than half the amount of cones specified in the contract.
- g. Minimum label on each container--species, locality, and exact period of collection.

A minimum contract for seed should state:

- a. Species, geographic source, year of collection, treatments applied, and minimum percentages of purity and of full seeds at time of delivery.

- b. Unit of measurement (usually pounds), and at least approximate moisture content at which seed is to be weighed.
- c. Price per unit, point and time of delivery, time of payment, and payer of shipping charges.
- d. Largest quantity the buyer will accept at contract price.
- e. Minimum label on each container--species, lot number, locality of collection, exact period of collection, method of extraction, storage conditions, and beginning and ending dates of storage. These minimum entries on the label are the indispensable basis for certain nursery and plantation records and for any system of seed certification (Baldwin, 1939; Baldwin and Shirley, 1936; Littlefield, 1939; Shirley, 1939)(____, ____, ____).

Prices for cones and seed may be difficult to set in advance of collection and extraction. In inviting or submitting bids, or entering other phases of bargaining, a feasible approach is to make the closest possible estimate, step by step, of the actual cost of the work, and then add 20 percent to the total for profit and risk.

Although they seem obvious, experience has shown that the following require emphasis. Warranty of species depends not only upon the integrity of the vendor, but also upon the training and integrity of his collecting crews. Warranties of species, geographic source, and date of collection involve not only adequate and accurate labeling, but also careful warehousing. The validity of germination percent statements depends upon the competence and facilities of the laboratory technician as well as the adequacy and soundness of sampling (p. 168).

If the buyer does not wish to rely solely on the vendor's ability or integrity for a statement of seed quality, the contract should specify how, when, where, and by whom the seed is to be sampled and tested, and what adjustment in price is to be made in the light of the test results.

Extracted seed is sometimes purchased from local collectors who lack good cleaning facilities. Such purchases are sometimes made on the basis of the weight after recleaning to specified standards. If so, the standards to which the seed is to be recleaned, and provision for inspection, sampling, and weighing, should be written into the contract.

A public agency buys cones or seed, or collects cones by contract, under regulations or restrictions peculiar to the individual agency. Any such restrictions should be fully explained to the vendor or contractor in writing. Vendors and contractors should inquire about restrictions before closing deals with public agencies.

Seed of longleaf, slash, loblolly, or shortleaf pine bought or sold in the State of Georgia must, with certain exceptions, conform to the Georgia Seed Law (p. 31).

Since even brief exposure to high temperatures and humidities during shipment may significantly reduce the vitality of seed, the precautions described on p.149 should be observed in shipping seed into or across the tropics.

Records

Seed records should include: species; lot number; geographic source (State and county or ranger district, with elevation above sea level where it exceeds 1,000 feet, and whether the seed came from a natural stand, a plantation of specified seed source, or a plantation of unknown source); date of collection; method and period of extraction; extent and method of cleaning; yield of clean seed per bushel; germination percent and moisture content when stored; temperature, humidity, container, date and duration of storage; and germination percent when removed from storage. Usually needed only when attempting to improve seed-handling techniques are records of: abundance of cone crop; yield of uncleaned seed per bushel; percentage of weight lost in cleaning; and the method and effect of pregermination treatment.